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PAPERS IN PRESS FOR FORTHCOMING ISSUES

NAVIGATION IN CRYSTALLOGRAPHY. By Horace Winchell

GEOMORPHOLOGY OF THE MIDDLE KERN BASIN, SOUTHERN SIERRA NEVADA, CALIFORNIA. By Robert W. Webb

CRYSTALLINE ROCKS OF SOUTHERN CALIFORNIA. By William J. Miller

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PETROGRAPHIC EXAMINATION OF CONCRETE AGGREGATES. By Richard C. Mielenz

TERTIARY AND QUATERNARY GEOLOGY OF THE LOWER RIO PUERCO AREA, NEW MEXICO. By Herbert E. Wright, Jr.*

Contains three colored maps: Geologic map of Lower Rio Puerco area, 16″ by 13″, scale about 1″ = 3 miles; Geomorphic map of Lower Rio Puerco area, 16″ by 15″, scale about 1″ = 3 miles; and Geologic map and structure sections of Lucero fault zone, 16″ by 7″, scale about 1″—2000′ ($.50 for set of three)

GEOLOGY OF THE NORTHWESTERN WIND RIVER MOUNTAINS, WYOMING. By C. L. Baker*

Contains colored geologic map of part of Fremont Peak quadrangle, U. S. G. S. topographic sheet as base. Scale, 1″ = 2 miles ($.25 each)

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MAP OF THE SOUTHWESTERN PART OF THE RAMONA QUADRANGLE

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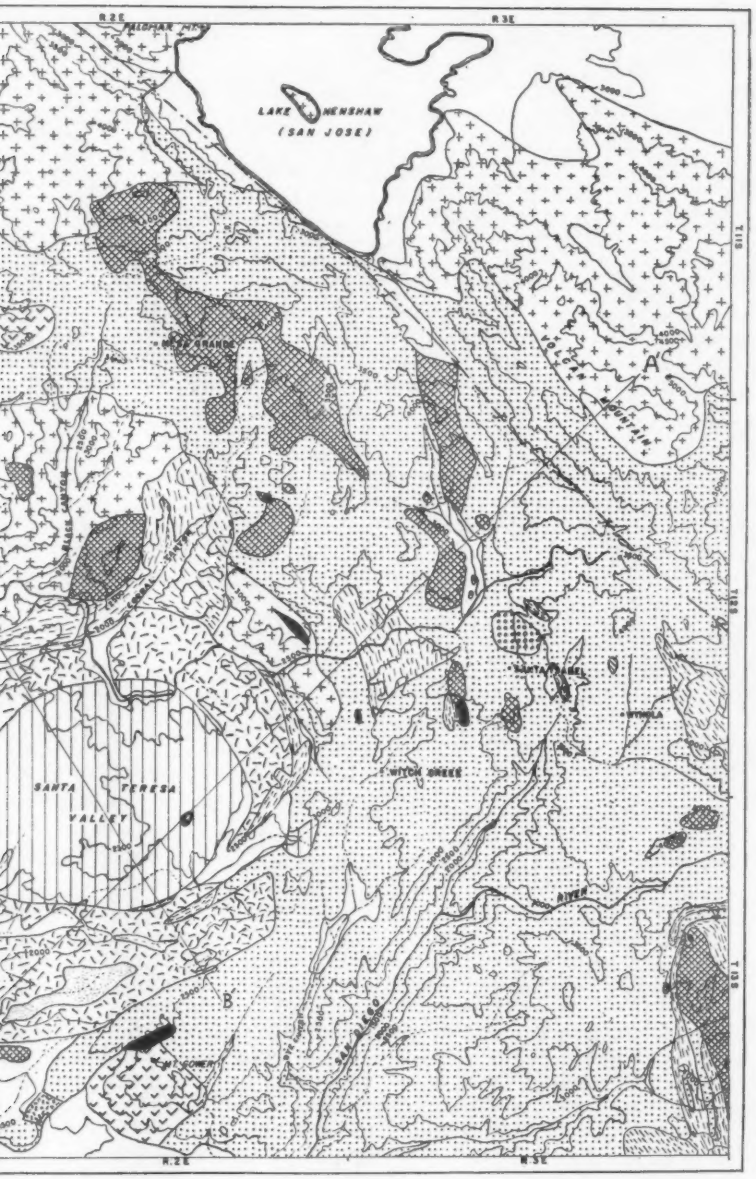
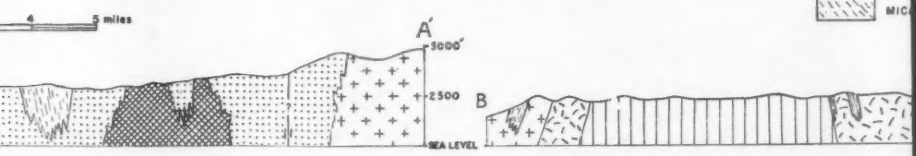
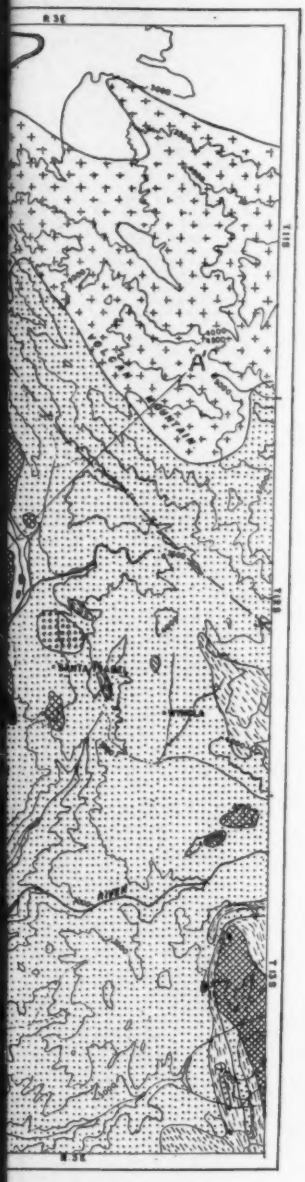




MAP OF THE SOUTHWESTERN PART OF THE RAMONA QUADRANGLE



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TOPOGRAPHY BY U.S. GEOL. SURVEY

RAMONA QUAD

ALLUVIUM

POWAY CONGL. EOCENE (TEJON)

WOLFORD GRANODIORITE

WOODSON GRANODIORITE

LAKEVIEW TONALITE

BONSALL TONALITE

GREEN VALLEY TONALITE

SAN MARCOS GABBRO

STONEWALL GRANODIORITE

STONEWALL QUARTZ DIORITE

MIDDLE CRETACEOUS?

QUARTZITE

AMPHIBOLITE

MICA SCHIST

JULIAN SERIES TRIASSIC?

THE RAMONA QUADRANGLE

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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IGNEOUS AND METAMORPHIC ROCKS OF THE SOUTHWESTERN PART OF THE RAMONA QUADRANGLE, SAN DIEGO COUNTY, CALIFORNIA

BY RICHARD MERRIAM

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ABSTRACT

The Ramona quadrangle is a central portion of the Peninsular Range of southern and Lower California. The geology of only a small part of this range is well known. It appears to be a large composite batholith with scattered roof pendants (chiefly metasedimentary rocks) and minor patches of Tertiary and Recent sediments along the margins. Tertiary volcanics are present in limited amount, but none crop out in the region here considered.

The oldest rocks of the area are Triassic(?) metamorphics, chiefly quartzite, quartz-mica schist, quartz-sillimanite schist, and amphibolite.

Associated with the schist is the Stonewall quartz diorite, which is older than all other intrusives of the region, but younger than the metamorphics. It intrudes the schist in a complex manner, the contacts between the two being indefinite and characterized by a wide zone of injection gneiss. Although much is a normal igneous rock, there are many places where the rocks show the effects of dynamic metamorphism.

Into the complex of schist and Stonewall quartz diorite was intruded a series of rocks ranging from gabbro to granodiorite, but with a predominance of tonalites. The order of intrusion is from mafic to felsic. There appears to be no systematic areal distribution except in a small central area where concentric arrangement suggests ring-dike structure. The batholith is of middle Cretaceous(?) age.

With the exception of the alluvium, the only postbatholithic formation in the area is the Eocene Poway conglomerate, small patches of which cap hills in the southern part of the quadrangle.

INTRODUCTION

LOCATION AND PHYSIOGRAPHIC SETTING

This report considers the southern half of the Ramona quadrangle, San Diego County, California, except for a narrow strip along the eastern edge. The western boundary of the area lies approximately 25 miles east of the Pacific Ocean, and the southern boundary is about 35 miles north of the Mexican border. The area covers about 340 square miles.

The Peninsular Range, of which the Ramona quadrangle is a central part, shows a wide range of physiographic types. Rugged peaks, table lands of low relief, deep gorges, and flat-floored valleys traversed by sluggish streams are closely related and apparently with little system.

From east to west the area consists of: (1) the flat-topped highlands of Volcan Mountain and Mesa Grande with the complementary lowlands, the vicinity of Wynola and Santa Ysabel and the box like valley of San Jose now occupied by Lake Henshaw; (2) the maturely dissected central belt, including Roderick Mountain and Pine Mountain in the north, Black Mountain and Santa Teresa Valley in the center, and Mount Gower and the vicinity of the headwaters of the San Diego River in the south and southeast; (3) the western terrace like tablelands of the Guejito and Santa Maria valley.

ACKNOWLEDGMENTS

The writer is indebted to Professor A. O. Woodford of Pomona College and Professor E. S. Larsen of Harvard University who suggested the problem. Thanks

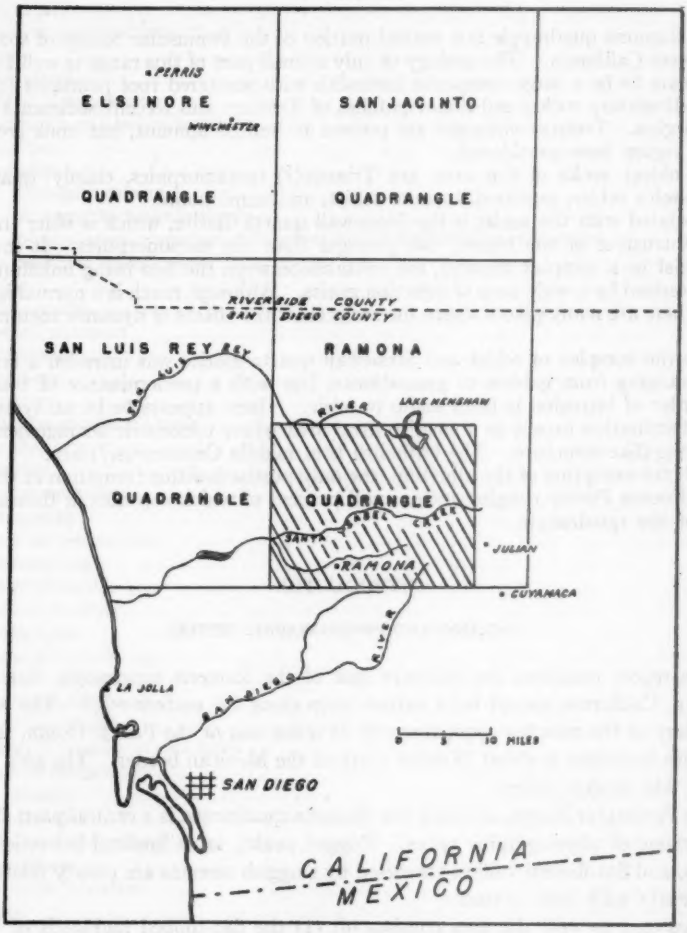

FIGURE 1.—*Index map*

are especially due Professor Larsen for the use of his unpublished map of the San Luis Rey quadrangle and for several analyses, thin sections, and samples of rocks from the region. Professors C. A. Anderson and Howel Williams of the Department of Geological Sciences of the University of California at Berkeley have given valuable advice and criticism.

GEOLOGIC COLUMN

Alluvium	Recent
Poway conglomerate	Eocene (Tejon)
Wolford granodiorite Woodson granodiorite Lakeview tonalites Bonsall tonalite Green Valley tonalite San Marcos gabbro	Middle Cretaceous (?)
Stonewall granodiorite Stonewall quartz diorite	Post-Triassic and Pre-gabbro
Julian schists	Triassic (?) and/or Paleozoic (?)

METAMORPHIC ROCKS

GENERAL STATEMENT

The metamorphic rocks can be subdivided into quartzite, schist, and amphibolite. Although these divisions are generally distinct, there are areas of mixed rock and zones of injection gneiss; thus the contacts shown on plate 1 are, in such places, largely arbitrary.

Metamorphic rocks occur throughout the area, but the largest bodies are in the east. Despite the widespread distribution, the remnants are too small and scattered to permit simple interpretation of regional structure or stratigraphy. With few exceptions, the strike is northwest-southeast, and the dips are steep. Deviations from this regional attitude are more common in the west and may have been caused by intrusions.

QUARTZITES

The quartzites are massive or laminated. The massive variety is usually associated with the granodiorites in which it forms streaks and lenses. This relation can be seen on a large scale on the map (Pl. 1), but the details of the complex and intimate mixing cannot be shown.

Nearly homogenous, structureless bands and lenses up to 300 feet thick form prominent reefs because of their superior resistance. Their massiveness is marred only by occasional thin dark streaks and swirls of biotite and magnetite, which may represent original cross-bedding.

Fine to medium, even, granular texture is characteristic. In the typical specimen subhedral or anhedral quartz 0.1 to 0.2 millimeters in diameter composes more than 80 per cent of the volume. Microcline is the most common feldspar, although andesine and orthoclase are also present. Poikilitic flakes of muscovite are sparsely distributed. Magnetite and almandine garnets are accessories.

The section exposed along Corral Creek has typical examples of the laminated type of quartzite. At least 3000 feet appears to be exposed here.

Individual bands in the quartzite vary in thickness from a fraction of an inch to several inches. The parting is invariably a layer of mica, chiefly muscovite, which

occurs sparsely within the quartzite itself. Locally there are no micaceous layers or parting, but alternate gray and white streaks may be distinct.

The quartzite near Sutherland contains small calcareous lenses 2 to 3 inches thick and 1 to 2 feet long, composed of a grayish-green granular aggregate of twinned crystals of calcite which include garnet, diopside, wollastonite, and brucite.

SCHISTS

The schists are more varied than the quartzites. They are dominantly quartz, two-mica schists which grade into the laminated quartzite. Other types are: quartz-sillimite schist, muscovite-sillimanite schist, and fissile muscovite schists. Excepting injection gneisses, there are no apparent contact effects. There is evidence of the introduction of material, but this action bears no relation to igneous contacts.

Wherever observed, the original bedding approximates the schistosity. Relict textures are lacking.

QUARTZ-MICA SCHIST

This type of schist is the most widespread of the metamorphic rocks. Locally, 3000 feet or more still remains. These rocks are commonly streaked gray, white, or brown. Their parting is well marked but discontinous, irregular, and foliated rather than smooth and slanty. In cross section, the color of the rock and distribution of the minerals may be uniform, but locally gray and white streaks a millimeter thick are well defined.

Polygonal or sutured grains of quartz make up at least 60 per cent by volume. Plagioclase, ranging from oligoclase to andesine, is present in varying amounts up to 10 per cent. Biotite and muscovite usually occur in approximately equal quantities, but either may greatly predominate in individual horizons. Inclusions of zircon with pleochroic halos are common in the biotite.

Fissile mica schist is common near Julian, and tongues of it extend westward into the area here considered. It is light gray or brown and has a good parting, which may be wavy or marked by fine crenulations. At least 30 per cent of this schist is made up of muscovite; biotite is present but subordinate, and granular quartz occurs in varying amounts.

SILLIMANITE SCHISTS

Although sillimanite schists are widespread, they aggregate much less than the quartz-mica schists or the quartzites. The best examples are in two small bodies a short distance east and south of Ramona. Other sillimanite schists crop out north of Witch Creek and 2 miles south of Mesa Grande. There appears to be no system in the distribution of these rocks. They do not necessarily occur near an igneous contact nor in the vicinity of any particular igneous rock type.

A variety of schists may be placed in this class: quartz-sillimanite schist, muscovite-sillimanite schist, quartz-cordierite-sillimanite schist, and garnet-sillimanite schist. Muscovite-sillimanite schist near Ramona is white, or light brown when weathered and distinctly foliated. Under the microscope, it is made up of flakes of

muscovite ranging up to 2 mm. in diameter and oriented roughly parallel to the schistosity. Sillimanite occurs as fibrous bundles and needles. Individual prisms 1 mm. long are uniformly distributed, but oriented at random. Individual grains and aggregates of yellow-brown rutile are widespread but amount to less than 5 per cent of the rock.

The quartz-sillimanite schist is hard and flinty, and, though visibly color-banded in shades of light brown, has little tendency to break parallel to that or any other plane. Thin sections reveal an aggregate of slightly lenticular quartz grains 0.1 to 0.2 mm. in diameter, with fibrous bundles and wisps of sillimanite lying chiefly at random, but with some approximating the long direction of the quartz lenses and forming more or less continuous streaks between the grains of quartz. The quartz carries abundant prismatic inclusions. Rutile occurs as in the muscovite-sillimanite schist.

The sillimanite schist south of Mesa Grande is relatively coarse-grained; crystals of sillimanite (1 to 2 cm.) and mica flakes (2 to 3 mm.) are abundant. Coarsely foliated schistosity is characteristic. Quartz makes up nearly half the rock, while plagioclase (approximately An_{40}) is present in minor amount. Biotite and muscovite are present, the former generally being more abundant. The sillimanite forms prisms. The larger prisms are approximately a third as wide as long, but the smaller are typical hairlike needles forming abundant inclusions in the quartz and micas. Magnetite grains are sprinkled throughout.

Andalusite schist, exposed in a road cut 2 miles east of Wynola is light gray, schistose, and fissile. The finer material is made up of quartz, biotite, muscovite, and sillimanite. Andalusite occurs as porphyroblasts, some partially surrounded by aggregates of coarse muscovite. Tourmaline and myremekitic intergrowth of quartz and feldspar are present in small amount.

AMPHIBOLITES

Amphibolites constitute less than 10 per cent of the metamorphic rocks and form a fairly distinct unit. Rarely they are mixed with other types.

These rocks are predominantly fine-grained and have a linear structure but poor planar schistosity. They range from light gray or green to black. Thin sections show a remarkably uniform texture and mineral composition. The texture is from fine to medium-grained and from granoblastic to nematoblastic. More than 50 per cent of the rock is blue-green hornblende with quartz and plagioclase (An_{10-40}). Magnetite and zircon are common accessories.

DIKES CUTTING THE SCHISTS

The schists are cut by quartz veins ranging up to 2 feet in thickness. Pegmatites are common and may be largely quartz with black tourmaline. The simplicity of mineral composition is in sharp contrast to that of the pegmatites in the younger rocks. Some pegmatites have been affected by dynamic processes, as, for example, a dike exposed in a road cut 1 and one-half miles east of Wynola. This is an irregular tabular body 2 to 3 feet thick lying approximately parallel to the nearly vertical schistosity.

Under the microscope, dynamic effects are very pronounced as the quartz is highly strained and nearly granulated; the feldspars have mottled extinction and bent twin lamellae. Quartz and feldspar have been drawn into large, roughly lenticular grains surrounded by aggregates of finer quartz grains, and muscovite flakes lie parallel to the direction of elongation. Only the smallest tourmalines show good crystal form, the larger ones having been broken into irregular grains.

ORIGIN OF METAMORPHIC ROCKS

There is evidence that material was introduced into many of the schists, but in most cases this has not been sufficient to obscure the original composition. Although metamorphism has largely destroyed the details of primary structures and textures, the general nature of the rocks is still apparent.

The quartizites were probably massive quartz sands, possibly cross-bedded as suggested by the curved dark streaks. Some of the sands were arkosic. Small lenses of calc-silicate minerals may originally have been limy concretions.

The abundant mica schists may have been well-bedded fine sands with shale interbeds. Silicic tuffs or tuffaceous sands may have given rise to thin streaks of muscovite-sillimanite schists (assuming the alumina was introduced.) The amphibolites may have been andesitic or basaltic flows. However, many of these rocks show fine, continuous banding with occasional thin streaks of light-colored material, suggesting derivation from tuffs or tuffaceous sands rather than from lavas.

The alumina of the sillimanite and andalusite-bearing schists may have been brought in by magmatic emanations from some of the younger igneous rocks, or, it may have been derived from original clay in the sediments. No contact zones, either mineralogical or textural, are apparent. The sillimanite and andalusite are not distributed with relation to igneous contacts. The sillimanite fibers and needles which roughly follow the parallel structure of most rocks are not necessarily oriented in that direction; instead they penetrate almost all other mineral grains at random. In a series of schists, the dense, fine-grained rocks such as quartzite may contain little sillimanite whereas the less compact, micaceous or porous types contain as much as 30 per cent. Other minerals of unquestionable magmatic origin are almost invariably associated with sillimanite and andalusite. For example, abundant, widespread rutile is found in the schists near Ramona. At other localities apatite, tourmaline, and large, randomly oriented flakes of muscovite with small 2V and low birefringence are probably of similar origin.

STONEWALL FORMATION

DISTRIBUSION

These rocks occur only in the eastern third of the area where they are more abundant than the schist and gabbro combined. This is only a minor extension of the formation; larger areas are known in the Julian and Cuyamaca regions. In the Ramona district, it forms the "matrix" in which are set small spots of gabbro and schist. As mapped, it includes slivers of schist too small and too intricately intermixed to be separated.

TYPES

Considerable variability is displayed by this formation. The most widespread type is foliated, gneissoid and in places approaches granite gneiss. The injection gneisses may be regarded as facies of this type and its distribution corresponds roughly with the distribution of the schist, as the two often are adjacent. In contrast to the gneissoid type are rocks which show little gneissoid structure. These occur largely where schist is most scarce and where the younger intrusives are most abundant.

A few bodies of gneissoid granodiorite are associated with the Stonewall quartz diorite, chiefly in Santa Ysabel Valley. The contacts are very indistinct, but probably they were intruded separately. The name "Stonewall granodiorite" was used by Donnelly (1934) to indicate the Cuyamaca-Julian complex to the east which he considered dominantly granodiorite but with some quartz diorite. Quartz diorite is dominant in the present area.

STONEWALL QUARTZ DIORITE

Normal phase.—This is medium- to coarse-grained and usually light gray. Dark schlieren are common. Although mostly massive and nearly structureless, parts show a preferred orientation of mineral grains, especially of the dark components.

The texture is phanerocrystalline, hypautomorphic granular. In most samples, highly strained quartz makes up approximately 40 per cent by volume. Plagioclase (An_{25} to An_{40}) usually comprises more than 50 per cent. Microcline was seen in one section. Biotite may show a slight parallel orientation. Hornblende is always present and in some places exceeds the biotite. Primary epidote, sphene, and zircon are acessory.

Gneissoid phase.—These are coarse- and medium-grained aggregates of quartz, plagioclase, biotite, and hornblende. Fresh specimens are medium to light gray, but weathering causes the rocks to become light reddish brown.

A marked streaking of dark bands and parallelism of dark minerals are the dominant structures. This arrangement often gives rise to a rough foliation or parallel parting. There are gradations from massive rocks to injection gneiss, paragneiss, and schist.

In addition to the megascopic gneissoid structure there is a textural parallelism revealed under the microscope. This texture is the result of bending of biotite flakes, crushing, and recrystallization of quartz and feldspar.

In most sections, plagioclase (An_{25-45}) is the most abundant mineral, amounting in some specimens to 60 per cent by volume. Potash feldspars arer are. Quartz, one of the chief minerals, appears as highly strained, nearly granulated crystals with sutured boundaries. Biotite is the chief ferro-magnesian mineral. Green hornblende is less common or may be lacking. Apatite, sphene, and zircon are the usual accessories.

STONEWALL GRANODIORITE

This rock shows distinct gneissoid structure, although less prominent than in many portions of the Stonewall quartz diorite. It is light-colored and lacks the red shade characteristic of the Stonewall quartz diorite.

In thin sections, the texture is granitic. There is much strained quartz, and streaks of finer-grained material surround the large grains.

Quartz, with undulatory extinction, makes up nearly 40 per cent of the rock. Orthoclase occurs in large grains, some which are perthitic. Oligoclase has very narrow twin lamellae. Muscovite is subordinate to biotite, but nearly always present. Apatite is the chief accessory.

INJECTION GNEISS

The injection gneiss is limited to the schist-Stonewall contact. The Stonewall rocks are usually gneissoid near the schists. The distinction between the gneissoid quartz diorite and injection gneiss is not sharp, and the relative importance of the two, which seems to vary from place to place is difficult to estimate. In general the injection rocks are less common and mainly consist of alternating bands of igneous material and mica schist, varying from a fraction of an inch to several inches in width The schist layers appear to be mineralogically identical with the usual quartz-mica schist. The material of igneous origin is chiefly quartz and plagioclase. The bands are usually straight and parallel, as in the original schist, but in some places intricate distortion and ptygmatic folding are characteristic.

CONDITIONS OF METAMORPHISM

GENERAL CONSIDERATIONS

The Stonewall rocks and the schists seem to have been affected in part by the same processes and are so closely related that a discussion of the origin of one must involve consideration of the other.

The absence of contact zones suggests that the schists were metamorphosed prior to intrusion by the Stonewall, unless the contact zones disappeared by stoping, which does not seem likely. Further evidence that the rocks were schistose before the intrusions is the extensive development of *lit-par-lit* injection gneisses. The metamorphic processes acting upon the schists prior to the igneous injections must have been widespread and uniform. The mineralogical composition and textures are typical of the mesozone as defined by Grubenmann (1924). Evidences of moderately high temperature and considerable pressure normal to the bedding planes are indicative. The emplacement of the Stonewall rocks was probably mainly by forceful injection, as evidenced by *lit-par-lit* injection in which the intercalated schist layers were probably mineralogically unchanged but mechanical distortion was common. There is no evidence of soaking of the schist layers in magmatic solutions. Porphyroblasts of new minerals are absent.

There is some indication of a period of deformation following intrusion of the Stonewall rocks. The strongest evidence suggesting post-intrusive deformation is the pegmatite-dike cutting of the schist northwest of Julian. These dikes intruded rocks already changed to schists and were later dynamically metamorphosed. There is a strong probability that the dikes belong to the same igneous cycle as the Stonewall intrusions. If so, the Stonewall intrusions should also have been affected somewhat. However, it is difficult to determine whether the gneissoid structure of

the Stonewall is the result of post-solidification deformation or merely the effect of movement during final emplacement of a partially solidified magma.

FIGURE 2.—*Petrofabric diagrams constructed from orientation measurements on 100 quartz grains in each rock*

Contour interval is one per cent. Black areas represent maxima.
(a) Gneissoid Stonewall quartz diorite.
(b) Gneissoid Lakeview tonalite.
(c) Massive Stonewall quartz diorite.
(d) Gneissoid Stonewall quartz diorite.

Gneissic structure of the Stonewall rocks is limited to the schist contacts. However, this could be the result either from drag effect during intrusion, or of deformation of a complex of schists and granitic rocks. The latter could produce foliation and gneissic structure in the intrusive along contacts where slipping would be greatest, leaving the centers of the igneous bodies relatively unaffected.

Figure 2 a, d are petrofabric diagrams of the Stonewall quartz diorite showing a maximum of gneissoid structure. A thin section of the specimen represented by

Figure 2, a shows considerable deformation, but other specimens (Fig 2c) exhibit almost no parallel structure; even in thin section there appears to be little distortion except straining of quartz. Figure 2, b is the diagram for a sample of tonalite, a part of the late Mesozoic batholith which shows no suggestion of dynamic metamorphism. Since the sample was taken close to a contact where streaking of dark inclusions and parallel orientation of feldspars and ferromagnesian minerals are marked, flow banding is distinct.

The quartz grains of the Stonewall rocks tend toward a definite orientation, whereas the tonalite shows a haphazard arrangement. Hence, it seems that the Stonewall rocks were deformed after solidification. There may have been a separate period of metamorphism, or the forces acting during intrusion may have continued after crystallization.

The events up to the time of intrusion of the younger batholithic rocks may be stated as follows: deposition of sediments, chiefly sands and shales with some volcanic material; regional mesozone metamorphism; intrusion of quartz dioritic and granodioritic magma, either accompained by protoclastic deformation or followed by a period of dynamic metamorphism.

AGE OF THE SCHISTS

Because of the scarcity of fossils, estimates of the age of the Julian series have been based mainly upon lithologic comparison with fossiliferous rocks elsewhere. Local relations indicate only that the schists are pre-Stonewall and therefore precede the general batholithic intrusive series.

There is conflicting evidence. The meager fossil evidence points to a Triassic age, while lithologically the schists are more like paleozoic rocks found elsewhere in the Peninsular Range. Possibly sediments of several ages are represented.

GABBRO

GENERAL CONSIDERATIONS

Gabbro and related rocks were described from the eastern edge of the Ramona quadrangle by Hudson (1922, p. 193–207) under the name "Cuyamaca basic intrusive". Miller (1937) described similar rocks in the San Luis Rey quadrangle, where he called them the San Marcos gabbro. Mapping of the Ramona area, which lies between the two above-mentioned areas, has shown that the two formations are probably the same. Although the rocks cannot be traced continously from one area area to the other, isolated patches are widespread in the intervening country. The names applied by Miller (1937) and Hurlbut (1935) in the San Luis Rey and Elsinore Quadrangles will be used in the present discussion. Hence, the gabbro will be called the San Marcos gabbro, even though Hudson was first to describe and name it.

TYPES

The San Marcos gabbro includes rocks of a wide range of composition and texture; yet there are nearly all gradations between the principal rock types. These types

are too intimately associated to be mapped separately. Among the many features which emphasize their close genetic relationship are: similarity of outcrops and local structural features; similar relations to the other rocks of the batholith; strong similarities in mineralogy; systematic variations in mineral content.

Medium-grained, dark-gray-green hornblende gabbro is the most abundant rock type, but norite is more representative of the average composition and texture. Rocks with a hypersthene-augite ratio greater than 2 to 1 are termed norites (Miller 1937, p. 1405). The norite locally grades to hypersthene gabbro. Other hornblende-poor types are olivine norites, olivine gabbros (eucrite), and troctolite. In contrast to these types are norite and a gabbro containing small amounts of quartz, although these are very rare. There are also considerable areas of hornblende gabbro and a small amount of quartz-biotite-hornblende gabbro.

DISTRIBUTION

The San Marcos rock occurs as numerous small bodies scattered among the younger and larger tonalite and granodiorite masses and as irregular patches cutting the schist and Stonewall rocks.

Field relations of the gabbro show that it intrudes the schists and Stonewall rocks. Local finer-grained facies are found near contacts, and injections into the schist with formation of metacrysts in the host rock were observed in a few places. The more silicic rocks of the region intruded the gabbro and probably removed much of it by stoping and assimilation.

OLIVINE GABBRO

Although quantitatively very subordinate, the olivine gabbro is of much genetic significance. It is a medium- to fine-grained, equigranular, structureless rock. It is dark gray and lacks the greenish tinge characteristic of the hornblende gabbro. The texture is typically "mosaic" (Miller, 1935, p.141).

Plagioclase is the most abundant mineral and constitutes 50 to 60 per cent of the average rock. Rarely, the rock is anorthosite. The feldspar forms polygonal crystals with broad twinning lamellae and is free from zoning. The composition is uniformly An_{90-95}. Inclusions and alterations are rare.

Olivine, approximately 25 per cent Fe_2SiO_4, makes up 5 to 15 per cent of the typical gabbro. It occurs as irregular rounded grains usually surrounded by a reaction rim of pale hypersthene which in some cases is enclosed by a zone of pale-green hornblende. The hornblende, which never exceeds 5 per cent, may form large poikilitic grains containing olivine and dark-green, vermicular spinel. Very pale-green augite is present in variable amounts up to 15 per cent.

With local increase in the amount of olivine and decrease of other ferromagnesian constituents troctolite is developed.

Hypersthene may be of sufficient abundance to merit naming certain types of olivine norite, though this is less common in the Ramona quadrangle than in the San Luis Rey quadrangle, where it is the most abundant type. Substitution of hypersthene for olivine may be great enough to produce eucrite.

HORNBLENDE GABBRO

Description.—Increase in hornblende and corresponding decrease of olivine and hypersthene give rise to a series of hornblende gabbros. In general they are coarser-grained than the olivine-bearing rocks, and some are porphyritic. They are dark gray or dark greenish gray, and, on account of their higher percentage of ferromagnesian minerals, they are somewhat darker than the olivine-bearing rocks.

Plagioclase, ranging rrom An_{45} to An_{85}, makes up 50 to 65 per cent of the average rock. It appears as irregular individuals which are generally larger than most of the other constituents, the latter being more or less interstitial. This contrast of sizes may be so extreme that the texture is prophyritic. Normal zoning in the plagioclase is especially marked in the more sodic phases and larger crystals. Very calcic (An_{90}) cores may be surrounded by a zone of An_{50-60}. Inclusions of augite or hornblende needles are common in the larger crystals. There has been little or no alteration of the feldspar, except for a thin zone directly exposed to weathering.

Augite is limited to small individuals or spotty remnants of large grains partly replaced by hornblende. The augite is pale but shows more color than that of the olivine rocks.

Pyrite is common in this group of gabbro to which it is almost limited.

Potash feldspar, quartz, and biotite occur only in phases which are transitional to the Green Valley tonalite, and, as they form a more or less distinct group, will be discussed separately.

Miller (1938) made a detailed study of the hornblende in the gabbro of the San Luis Rey quadrangle and distinguished four main types, all of which have been found in rocks of the Ramona area.

Miller has classed the hornblendes as: (1) pale-green hornblende, (2) deep-green reaction hornblende, (3) green-brown poikilitic hornblende, and (4) pale, fibrous, and blue-green hornblende. As shown in Figure 3, the optical properties of these bear a distinct relation to the anorthite content of the associated plagioclase. The higher the calcium content of the plagioclase, the lower the index and iron content of the hornblende. There is a similar, but less distinct, relationship between the augite, hypersthene, and feldspar.

Pale-green hornblende.—This variety occurs chiefly in the olivine rocks where it forms reaction rims around olivine. It is also interstitial between the plagioclase grains or is poikilitic, enclosing small plagioclase grains or pyroxenes. Some is intergrown with vermicular spinel in reaction rims around olivine (Pl. 2, fig. 3). These intergrowths may have been formed by reaction between olivine and plagioclase or by direct crystallization from a liquid which had passed into the spinel field of Bowen's (1928, p. 278–279) equilibrium diagram. Although much of the pale-green hornblende was obviously derived from reaction between the residual liquid of the crystallizing magma and previously formed pyroxenes, as shown by isolated, similarly oriented patches of pyroxene within a larger hornblende crystal, part is probably from primary crystallization.

Deep-green reaction hornblende.—This hornblende is found principally in the norites or related gabbros. It is a compact, deep-green variety, strongly pleochroic in shades

of green. It replaces hypersthene and augite in all stages ranging from narrow rims to large individuals enclosing poikilitic remnants of pyroxene. Such poikilitic hornblendes may be optically continuous in grains 4 to 5 mm. across. The replacement of hypersthene is commonly in sharp zones but with augite irregular spots may also develop in the interior of an augite crystal. There is little doubt that most, if not all, of this deep-green hornblende was formed from previously crystallized pyroxenes.

Green-brown poikilitic hornblende.—The hornblende gabbros contain this type of hornblende in abundance, but it is also found in a few of the olivine rocks and norites. It is moderately pleochroic from greenish brown to brownish green, usually occurring as large poikilitic crystals, some 5 to 6 cms. long. Apparently crystallizing directly from the magma at a very late stage, it encloses grains of nearly all minerals.

Pale, fibrous, and blue-green hornblende.—These hornblendes are practically limited to the hornblende-rich gabbros. The pale, fibrous variety is very faintly pleochroic, colorless to pale green, and may be classed as secondary actinolitic type or uralite. The associated nonfibrous, blue-green hornblende forms clusters of minute, irregular grains and is strongly pleochroic from blue-green to yellow-green. These types of hornblende are interstitial to the other minerals and occur in irregular patches and aggregates of grains or fibers; they penetrate the plagioclase grains and fill veinlets. Their distribution is largely controlled by fractures. Plagioclase, pyroxene, and olivine are replaced by these hornblendes which are commonly associated with chlorite. These facts indicate that they were formed from hydrothermal solutions which migrated along joints of an already solidified rock.

There is also a distinctive variety which occurs as narrow needles in the gabbro of Santa Ysabel Valley. These needles make up 40 to 50 per cent of the rock and are randomly oriented. They average a centimeter in length by a millimeter in thickness, but some nearly pegmatitic phases of the gabbro carry crystals up to 10 cms. long. Although the needles appear in the hand specimen to be automorphic and bounded by prism faces, under the microscope they are seen to be molded against the plagioclase. Pleochroism is Z = deep bluish gray, Y = yellow green, X = pale greenish yellow. Locally inclusions of magnetite are abundant, some oriented with respect to the cleavage.

QUARTZ-BIOTITE-HORNBLENDE GABBRO

Although these rocks form but a small portion of the gabbro, they are important because they form an end member of the gabbro series. The only extensive area of this type of rock is approximately 2 miles east of Mesa Grande. No sharp line of demarcation can be seen against the adjacent hornblende gabbro, although exposures continue uninterruptedly from one type to the other.

Texturally, the quartz-biotite-hornblende gabbro is somewhat like the average norite or hornblende gabbro; the difference lies in the mineralogical composition. Plagioclase (An_{45-55}) makes up 55 to 60 per cent of the rock. Crystals with calcic cores are more frequent than in any other type of gabbro. Quartz, in anhedral interstitial grains, ranges from 5 to 10 per cent, while dark-brown biotite is usually present in about the same amount. Olivine never exceeds 5 per cent. Both augite

and hypersthene are important minerals and Miller found that these minerals, in the corresponding rocks of the San Luis Rey quadrangle, contain relatively more iron than those in the more calcic rocks.

CHEMISTRY

Although no analyses have been made of the gabbro of the Ramona quadrangle, the analyses of many samples from the San Luis Rey quadrangle have been published by Miller. Comparison both in the field and in the laboratory shows that these analyses represent fairly well the composition of corresponding rocks of the Ramona region. Table 1 presents the analyses, modes, and norms of the most common types given by Miller (1937, p.1412), F. A. Gonyer, analyst. Some of the chief features of these analyses are: (1) the high percentage of Al_2O_3; (2) the high percentage of CaO in the olivine rocks; and (3) the gradual decrease in MgO and increase in total iron with increasing silica content.

STRUCTURE

Banded structure—Limited portions of the hornblende gabbro exhibit distinct banding. The bands consist of dark and light parallel streaks which in most rocks bend in broad sweeping curves. Individual dark bands avarage from 0.5 to 1 mm. in width and may divide and rejoin or coalesce with other bands to produce a braided appearance. However, uniform parallel banding is equally as common. The dark bands are generally two or three times as wide as the light bands and contain large amounts of hornblende, while the light bands consist almost entirely of plagioclase. Contacts between bands are gradational; mineral grains interlock across the boundary and there is no great difference in texture. The bulk of the mineral composition is not different from that of the average massive hornblende gabbro. The plane of banding is variable, but is in most places nearly vertical. The distribution of the structure bears no relation to contacts.

Of the various theories to explain primary banding of basic igneous rocks, that of differential flowage of a heterogeneous magma is the most logical. However, it is difficult to picture the conditions which might give rise to a heterogenous magma. The bulk composition of the rock is the same as that of the average gabbro, thus eliminating the possibility that the banding represents streaked inclusions of foreign material.

It may be that there was early crystallization of plagioclase around centers, leaving a liquid phase poor in felsic material and rich in mineralizers. That such crystallization around centers did occur in the gabbro is shown by the orbicular and nodular structure found in these rocks in the San Luis Rey and Cuyamaca quadrangles (Miller, 1938, p. 1224-1229; Lawson, 1904). Movements causing flowage might then streak the area rich in plagioclase into bands separated by liquid material which later crystallized to form the dark, hornblende-rich bands. Flowage past a local obstruction or constriction would accentuate the streaking or banding.

Auto-injection structure.—This small-scale structure was observed only at the north end of the Santa Ysabel Valley. The term auto injection has been applied to the

TABLE 1.—*Analyses, modes, and norms*

	I	II	III	IV
ANALYSES				
SiO_2	42.86	48.16	52.12	58.68
TiO_2	.18	.76	.33	.68
Al_2O_3	24.94	19.66	20.88	17.32
Fe_2O_3	2.13	1.53	.34	1.36
FeO	6.14	5.06	6.52	5.06
MnO	.06	.14	.09	.08
MgO	9.28	7.59	6.90	4.46
CaO	13.08	13.46	10.14	7.52
Na_2O	.76	1.88	2.40	2.96
K_2O	.09	.31	.25	1.20
H_2O+	.78	1.48	.22	.67
P_2O_5	—	.11	—	.06
S	.03	.08	—	.02
	100.33	100.22	100.19	100.07
MODAL COMPOSITION OF THE GABBROS				
	(per cent by volume)			
Plagioclase	67	47	65	55
K feldspar	—	—	—	—
Quartz	—	—	—	16
Biotite	—	—	—	8
Hornblende	11	46	0.9	10
Pyroxene	2	6	33	9
Olivine	18	—	—	—
Fe ore	0.2	1.9	1.7	3
Spinel	2	—	—	—
Iddingsite	0.2	—	—	—
Chlorite	—	0.1	—	—
	100.4	101.0	100.6	101
NORMATIVE COMPOSITIONS OF THE GABBROS				
Q	—	—	1.26	12.30
Or	.56	1.67	1.11	7.23
Ab	6.29	16.24	20.44	25.15
An	64.22	44.20	45.59	30.30
C	—	—	—	—
Di	.68	17.39	3.76	5.66
Hy	4.09	9.18	26.53	15.34
Ol	20.09	6.01	—	—
Mt	3.02	2.09	.46	2.09
Il	.46	1.52	.61	1.37
Py	—	.12	—	—
Ap	—	.34	—	—

I = Olivine norite, San Luis Rey Quadrangle
II = Noritic hornblende gabbro, San Luis Rey quadrangle
III = Typical norite (hornblende free), San Luis Rey quadrangle
IV = Quartz-biotite-hornblende gabbro, San Luis Rey quadrangle

gabbro which is composed of two distinct phases, one medium- to fine-grained, not unlike the average hornblende gabbro, the other coarse-grained, nearly pegmatitic. The latter penetrates the former in highly irregular forms, usually with crystals interlocking across boundaries. The difference between the two phases is mainly textural, although more hornblende may occur in the coarse part. The relative proportions of the two phases may show considerable local variations. The finer types are, in some places, very subordinate in amount and form irregular angular patches within the interstitial coarse portion. In another variety of auto injection irregular veinlike structures of the coarse gabbro penetrate the finer phase. The coarse injections are 1 to 10 cms. or more in width and carry hornblendes up to 5 cms. long. Miarolitic cavities contain 1- to 2-centimeter plagioclase crystals.

Miller's explanation seems quite adequate to account for this occurrence. He holds that the structure resembling intrusion breccia was produced by local shattering of early solidified portions of magma and infilling between the detached fragments by the liquid magma. He suggests, further that the veinlike, irregular penetration of one phase by another was formed when the earlier phase was still a crystal mesh. A new intrusive impulse may have separated the mesh and forced into it not merely the interstitial liquid from the mesh but also liquid magma from adjoining portions of the body.

DIKES

Pegmatites and lamprophyres cut the gabbro. The well known gem pegmatites of Pala occur in the gabbro just west of the Romona quadrangle and some of the lithium pegmatites of Mesa Grande cut the gabbro. These have been described by Kunz (1905, p.135–150) and Schaller (1925).

The lamprophyres are only locally abundant and rarely exceed a foot in thickness. They are most numerous in the olivine gabbro. One common type is spessartite. It is a fine, even, granular, compact, dark rock with an average grain size of 0.1 to 0.2 mm. Under the microscope the texture appears to be panidiomorphic. The chief mineral is calcic plagioclase (An_{90}) which constitutes approximately half the rock. Brownish-green hornblende makes up most of the remaining 50 per cent, although augite and magnetite are present in small amounts. No olivine was seen.

A second type of lamprophyre is beerbachite. This rock is quite similar in texture and general appearance to the spessartite, but nearly 30 per cent is made up of strongly pleochroic hypersthene. Augite is less abundant with less than 10 per cent in the average section. The plagioclase is approximately An_{75}. Magnetite is the chief accessory.

GREEN VALLEY TONALITE

GENERAL CONSIDERATIONS

With the exception of a small area near Ballena in the east-central part of the area, the Green Valley tonalite is limited to two large masses: (1) a nearly circular body approximately 4 miles in diameter near the center of the area, and (2) a somewhat larger, irregular body in the western part of the quadrangle.

Locally this tonalite grades into the gabbro. The relation of the Green Valley

tonalite to the Bonsall tonalite is equally indefinite, and it is difficult to determine their relative ages. Dark inclusions in the Bonsall tonalite are slightly more abundant near the contact with the Green Valley, but whether or not they come from the latter cannot be proved. More suggestive evidence is found in their relation to the gabbro. The Green Valley is entirely gradational into the gabbro, whereas the Bonsall is distinctly younger and contains abundant inclusions of the gabbro. Contacts between the gabbro and Bonsall are not sharp, and hybrid zones may be several hundred feet wide. However, the more basic Green Valley magma should assimilate the gabbro more readily and thus produce more gradual contacts.

PETROGRAPHY

The Green Valley tonalite is a uniform, medium-grained plutonic rock. It ranges from light to dark gray, the latter being more characteristic and mainly due to the gray feldspar. The rock is notably massive and structureless, and occasional dark inclusions are not streaked, but irregular. Large poikilitic biotites with sieve structure and continuous cleavage surfaces of 1 to 2 cm. are prominent on fresh fractures.

In thin section, the Green Valley tonalite is characterized by abundant, partly replaced grains. Examples are augite, replaced by hornblende, and calcic plagioclase, replaced by sodic plagioclase. The texture bears evidence of later readjustments in its many poikilitic minerals such as hornblende and biotite.

Approximately 50 per cent of the rock is plagioclase (An_{40-56}), most of which is only slightly or not at all zoned. In addition to these more or less tabular, unzoned crystals, there are numerous plagioclases with one or two calcic (An_{85-90}) zones, or with cores of that composition. Other unhomogeneous grains are less regular and show mottled extinction or have rectangular patches of calcic composition set in a large, more sodic envelope. A few plagioclases show oscillatory zoning. The calcic zones or cores tend to alter to saussurite. Inclusions of magnetite, biotite, hornblende, and augite are locally abundant and are generally concentrated in the more calcic portions

Quartz occurs in variable amounts, from an average of 20 per cent to less than 10 per cent. All grains are anhedral, have sharp extinction, and some contain many small needlelike inclusions.

Hornblende makes up approximately 10 per cent of most sections. It forms separate individuals of uniform composition, some of which are poikilitic. It is also found as reaction zones around augite. Optical properties indicate a moderate iron content.

There is rarely more than 1 to 3 per cent augite. It is colorless, nonpleochroic, and commonly twinned parallel to (100). The mineral appears as discrete, nearly equant grains or as irregular cores of large hornblendes.

Hypersthene is limited to the darker phases of the rock and never exceeds 5 per cent. It forms separate grains or is partly replaced by hornblende.

Biotite is the most prominent ferromagnesian constituent, amounting to as much as 15 per cent of most specimens. Although small shreds are found, the most common form is the large, poikilitic, "sieve structure"; flakes range up to 6 mm. in diameter.

Zircon, sphene, apatite, and magnetite are abundant accessories.

CHEMICAL COMPOSITION

No analyses of the Green Valley tonalite from the Ramona quadrangle have been made, but the following analysis made by Gonyer and quoted by Miller (1937, p. 1412) is of a sample from the type locality in the San Luis Rey quadrangle. It is a normal tonalite. Although this analysis may be taken as representative of the composition of much of the Green Valley tonalite of the Ramona region, thin-section study indicates that less silicic phases are common.

DIKES

Many pegmatites cut the tonalite. Some have yielded considerable amounts of tourmaline, garnet, beryl, topaz, and other gems. Kunz (1905, p. 140–150) noted these dikes but gave no geological description. They are vertical or steeply dipping bodies ranging from 2 to 8 feet in thickness and traceable in some places for

TABLE 2.—*Analysis of Green Valley tonalite from roadcut two miles west-northwest of southwest corner of Ramona quadrangle*

		MODE (volume percentage)	
SiO_2	63.70	Plagioclase	48
TiO_2	.57	K feldspar	—
Al_2O_3	15.32	Quartz	24
Fe_2O_3	1.58	Biotite	13
FeO	4.25	Hornblende	10
MnO	.09	Pyroxene	4
MgO	3.18	Iron ore	0.9
CaO	5.68		
Na_2O	3.00	NORM	
K_2O	1.92		
H_2O+	.67	Q	20.88
P_2O_5	.06	Or	11.12
S	.02	Ab	25.15
	99.86	An	22.80
		C	—
		Di	4.54
		Hy	11.35
		Ol	—
		Mt	2.32
		Il	1.06
		Py	—
		Ap	—

several hundred yards. The largest part of most dikes is a medium-grained, almost aplitic aggregate of quartz, microcline, and oligoclase. Some phases are graphic and coarser-grained. Other phases, near the centers of the dikes, are coarse-grained and carry black tourmaline, garnet, and biotite. Some dikes are cut by irregular veinlets 2 to 4 inches wide composed of coarse quartz and feldspar. Wide places in the veinlets contain black tourmaline in the center, some crystals reaching 2 inches in diameter. Banding is always apparent and locally is very striking. Numerous, thin wavy bands are produced by lines of garnets or fine tourmaline crystals imbedded in the aplitic matrix. Some bands are rich in muscovite, with many of the flakes oriented normal to the bands. Tourmaline needles 1–2 centimeters long also cut across the banding.

The origin of the banding is conjectural. The process may have been similar to diffusion in the broad sense. At an early stage, much of the dike was probably more or less aplitic. Some connection with the parent magma was maintained

through which pneumatolytic and later hydrothermal solutions passed. From these solutions there may have been a pulsatory, rhythmic escape of mineralizers which formed the bands of garnets, tourmaline, and muscovite by replacement. Locally, abundant large feldspars or masses of graphic quartz and feldspar cutting indiscriminately across the bands suggest later formation by metasomatic replacement.

A few small dikes in the easternmost mass of Green Valley tonalite are 1 to 6 inches thick, crop out for a few tens of feet, and are composed of a central band of fine tourmaline needles between coarse outer bands consisting of a mixture of quartz and oligoclase, the latter being untwinned for the most part and forming crystals 1 to 2 cms. in width. Small spessartite garnets are sparsely distributed.

BONSALL TONALITE

GENERAL CONSIDERATIONS

This rock type was named for a small town in the San Luis Rey quadrangle, at the type locality, by Hurlbut (1935) who has published the only detailed description of the rock.

The Bonsall tonalite is probably the most extensive rock of the Peninsular Range, certainly among the batholithic rocks. There are approximately 180 square miles in the San Luis Rey quadrangle, and considerable areas are known in the Elsinore, San Jacinto, and the northern part of the Ramona quadrangles. Probable correlatives in these quadrangles are the Perris quartz diorite described by Dudley 1936) and the Val Verde tonalite studied by Osborne (1939).

TYPES

There is a considerable range in the proportions of mineral constituents, but all types fall well within the restricted range of the tonalites. The most abundant type is an average tonalite. Less silicic forms occur in the region of Pine Mountain and eastward toward Mesa Grande. The northwest end of Volcan Mountain and the rocks near Ramona are of the silicic variety, which, on account of the deficiency of dark minerals, is much lighter in color.

PETROGRAPHY

The dominant type is medium, even-grained and light gray. In some places it is massive, but commonly it shows marked banding as the result of parallel orientation of the plagioclases and ferromagnesians and the streaking of dark inclusions. The less silicic variety is slightly finer-grained and contains a higher percentage of ferromagnesians. More distinctive is the leucocratic type which, in extreme cases, appears to be an entirely separate rock, but a sharp contact has never been found between it and the normal type.

The grain size of all constituents is approximately the same; the texture is hypautomorphic granular. Zoned plagioclase makes up at least 50 per cent of the rock and in some cases ranges up to 65 per cent with a corresponding decrease of quartz. The composition of the feldspar ranges from An_{38} in the leucocratic type to An_{50} in the melanocratic. Oscillatory zoning is most marked in the feldspars of the leucocratic rocks but is found in all types. The more basic variety commonly shows crystals with very calcic cores.

Orthoclase is widespread but of minor importance. In the leucocratic rocks, where it is more abundant, it rarely exceeds 5 per cent of the rock. The mineral is uniform and exhibits sharp extinction. Carlsbad twins occur occasionally. Myrmekitic borders are present, a complete crystal sometimes being replaced by the intergrowth. Hornblende constitutes 10 per cent of the normal rock but may be nearly lacking in the silicic type.

Biotite is always present, ranging up to 15 per cent. The mineral is rarely euhedral but is more commonly found as ragged flakes and shreds grouped in aggregates with hornblende. Exceptionally, biotites 0.5 to 1.0 cm. in width occur, especially in the lighter phases. Such flakes invariably carry abundant inclusions of plagioclase. Streaks within some grains of the biotite have altered to green, pleochroic chlorite.

Quartz constitutes 20 to 25 per cent of the average rock. Irregular, large grains with sharp extinction or undulatory aggregates show mortar structure, as in the rocks of Volcan Mountain and vicinity.

Pyrozenes are notably rare except in the melanocratic phases of the rock, where they may compose between 5 and 10 per cent of the specimen. These pyroxenes are probably the result of assimilation of gabbroic material. Both augite and hypersthene are present in roughly equal amounts and appear in similar habits. Irregular zones of green hornblende usually surround both pyroxenes. The hornblende of a zone is uniformly oriented, the pyroxene making up an irregular core of a larger hornblende crystal.

Sphene is the most abundant accessory, some crystals reaching 3 to 4 mm.; the mineral is not, however, universally present. Apatite and zircon are more widespread accessories.

CHEMICAL COMPOSITION

The analysis (Table 3, No. I) is given by Hurlbut (1935, p. 613) for a typical variety of the Bonsall tonalite from the San Luis Rey quadrangle. Analysis No. II was furnished by Larsen and is of a leucocratic variety found at Oak Grove, Ramona quadrangle. F. A. Gonyer made both analyses.

RELATION TO ADJACENT ROCKS

Rocks younger than the Bonsall are usually in sharp contact with it, but the boundaries between the Green Valley tonalite or the San Marcos gabbro and the Bonsall are vague. These rocks are adjacent over long distances, but it is impossible to trace the exact contact even 100 yards. There are places where a continuous traverse can be made from one rock to the other through a gradational zone several hundred yards wide. Even the rock which is almost entirely of pure Bonsall type usually contains many streaked, dark inclusions which become more abundant toward the contact with the darker rocks. Hurlbut held that these inclusions were derived from the gabbro.

STRUCTURE

The orientation of inclusions and minerals gives an indication of the movement during emplacement. The most notable large-scale structural feature is the tendency for the flow planes to parallel older structural lines. Such lines predominantly strike northwest-southeast, and Hurlbut suggests that possibly forces producing them continued during emplacement of the Bonsall.

INCLUSIONS

General statement.—Hurlbut (1935) studied the inclusions in the Bonsall tonalite of the San Luis Rey quadrangle and arrived at a fairly definite conclusion, which is substantiated by the present study.

TABLE 3.—*Analyses of Bonsall tonalite*

	NO. I	NO. II
SiO_2	64.86	69.72
TiO_2	.55	.34
Al_2O_3	17.46	16.68
Fe_2O_3	1.80	1.27
FeO	2.80	1.29
MnO	.30	.03
MgO	1.36	.66
CaO	5.26	3.74
Na_2O	3.38	3.94
K_2O	1.64	1.32
H_2O-	.50	.16
H_2O+	.05	.53
P_2O_5	—	.08
S	—	.07
	99.96	99.83

	MODE (Volume percentage)		NORM					
	I	II		I	II		I	II
Plagioclase	49	52						
K feldspar	4	2	Q	24.86	32.04	Hy	6.17	3.86
Quartz	25	36	Or	9.45	7.78	Ol	—	—
Biotite	15	9	Ab	28.82	33.40	Mt	2.55	1.84
Hornblende	7	—	An	26.13	18.60	Il	1.06	0.61
			C	.61	1.94	Py	—	—
			Di	—	—	Ap	—	—

Locally, inclusions amount to 30 per cent of the rock, but 8 to 10 per cent is the average. Rarely they are entirely lacking. A maximum length of 2 feet is seldom reached, and a minimum of 2 inches is equally uncommon. Their shapes are variable, but the majority are lenticular. Irregular inclusions occur in massive tonalite, whereas streaked or lens-shaped inclusions are found in rock exhibiting parallel orientation of mineral grains, as along contacts with older rocks.

Petrography of the inclusions.—The inclusions are dark gray, uniform, and have a fine, sugary texture with sparse plagioclase metacrysts. Boundaries between inclusions and host appear sharp to the unaided eye, but, with a lens, grains of the tonalite can be seen penetrating the inclusions.

In thin section, the texture is panidiomorphic. Plagioclase averaging An_{40-45} constitutes up to 50 per cent of most sections, but calcic cores (An_{85-90}) are not rare. The remainder of the inclusions consists of quartz (30–40 per cent), hornblende prisms, and poikilitic biotite. Hypersthene or augite may be present in small quan-

TABLE 4.—*Comparison of indices in Bonsall tonalite and inclusions*

	INCLUSIONS	TONALITE
Hornblende	α 1.645–1.660	α 1.648–1.668
	β 1.650–1.665	β 1.660–1.680
	γ 1.660–1.680	γ 1.670–1.685
Biotite	γ 1.650–1.665	γ 1.645–1.660

TABLE 5.—*Modal composition*
(Per cent by volume)

	BONSALL TONALITE	INCLUSIONS	GABBRO
Quartz	27	3	Trace
Orthoclase	4	1	0
Plagioclase	50 (An_{40})	58 (An_{62})	65 (An_{80})
Biotite	12	15	Trace
Hornblende	7	22	13
Augite	Absent except in hybrid facies	Trace	11
Hypersthene		Trace	11

ties. Reaction rims of biotite around hornblendes, or of hornblende around pyroxenes, are common.

Mineralogic comparison of inclusions with Bonsall tonalite and gabbro.—The minerals of the inclusions and those of the host rock are, in general, similar, but certain significant differences exist. Tabel 4 brings these out.

Both the qualitative and quantitative mineral compositions are important in determining the source of the inclusions; hence Table 5 is included.

Source of the inclusions.—The comparison of mineral compositions strongly suggests that the gabbro is the source of the inclusions. The calcic cores in some of the plagioclases of the latter could have come from no other known rock of the region. Likewise, the pyroxenes indicate material which could not have come from the tonalite. Whether the source was the gabbro exposed at the surface, or some other deeper-seated body through which the tonalite passed, cannot be determined.

DIKES

Dikes cutting the Bonsall tonalite are almost exclusively pegmatites. The most common are composed largely of quartz and microcline with muscovite, biotite, and and black tourmaline in smaller amounts. Spessartite garnet is a common accessory. Banding parallel to the wall rock is distinct. The outer zones are invariably fine-

grained and may be nearly aplitic, but the center is much coarser and usually contains a greater variety of minerals.

LAKEVIEW TONALITE

GENERAL STATEMENT

This name was originally used by Dudley (1935, p. 502) for rocks of the Perris region, and its application here is merely because of lithologic similarity. It does not imply that the rocks of Perris and Ramona were derived from a common magma, but rather that they are the same types of tonalite. The Lakeview tonalite of Ramona has been described previously (Merriam, 1941).

TABLE 6.—*Modal and chemical composition*

SiO_2	66.5		
Al_2O_3	17.2	Plagioclase (An_{33})	52
Fe_2O_3	2.0	Quartz	26
FeO	3.7	Biotite	10
MgO	2.0	Hornblende	10
CaO	4.7	K feldspar	1
Na_2O	3.4		
K_2O	1.4		

The entire extent of the Lakeview is in a ring-shaped area, northeast of the town of Ramona, and does not exceed 20 square miles in surface exposure.

PETROGRAPHY

The texture is phanerocrystalline, hypautomorphic granular, with average grain sizes of 2 to 3 mm. It is distinguished by its abundant white feldspar and its ferromagnesians which are commonly euhedral. The hornblende usually equals or exceeds the biotite. In this respect the Lakeview tonalite differs from the other tonalites. The rock varies in color, but in general it is light gray or white, speckled with clean-cut ferromagnesians. Specimens near contacts are markedly gneissoid.

The texture is equigranular, nearly all minerals being either subhedral or euhedral. Myrmekitic intergrowths are widespread but occur only as small patches.

Plagioclase (An_{33-45}) is the most abundant mineral and makes up at least half the rock. Orthoclase was found in nearly every section, but makes up less than 5 per cent of the rock. Quartz, with minute, randomly oriented, prismatic inclusions, composes at least a fourth of the rock.

Hornblende is the most important dark mineral. It differs little from that in the other tonalites, except that some grains are euhedral or automorphic in the prism zone. Streaks altered to chlorite occur in many grains. Biotite occurs in shreds, irregular flakes, or, more rarely, as hexagonal plates. Streaks in some flakes are altered to chlorite. Epidote, formed by saussuritization and as a primary mineral, is widespread and composes up to 2 or 3 per cent of the rock. The primary type appears as large, irregular grains closely associated with the ferromagnesians and in some cases enclosed by hornblende. Sphene, apatite, and zircon are accessory minerals.

Table 6 gives the modal composition and the approximate chemical composition calculated therefrom.

INCLUSIONS

Dark inclusions, similar to those in the Bonsall tonalite, are present throughout most of the Lakeview but are most abundant and largest near the contact with the Green Valley tonalite. Apparently the schist bodies have yielded comparatively few xenoliths, for there is only a narrow zone of partially separated slabs and leaves more or less in their original form and composition. The following discussion will be limited to the dark inclusions of uniform composition and texture characteristic of the Green Valley tonalite contact.

With very few exceptions the dark inclusions are discoid, appearing lenslike in the horizontal and vertical section normal to the Green Valley contact. However, vertical sections tangent to the contact show the inclusions as irregular subcircular bodies. Those toward the interior of the intrusion are streaked out into thinner lenses than those near the contact. Some larger inclusions are surrounded by a zone of smaller ones apparently detached during flowage of the magma.

The texture of the inclusions is porphyroblastic with a fine, even-granular groundmass and sparse, well-distributed metacrysts of plagioclase and biotite.

In thin section a granoblastic aggregate of hornblende, plagioclase, biotite, and quartz forms a groundmass in which are set poikilitic porphyroblasts of plagioclase and biotite. Plagioclase occurs as small, equant grains in the groundmass and as porphyroblasts 1 to 5 mm. wide. Calcic, corroded cores or irregular, calcic zones are common.

Hornblende comprises nearly 20 per cent of most inclusions. Biotite ranges from small shreds to larger (5 mm.) poikiloblasts. Magnetite, apatite, and zircon are widespread.

STRUCTURE

Except for the gneissoid structure near contacts, the Lakeview lacks small-scale structures. The circular surface distribution and probably roughly cylindrical form of the intrusion largely determine the large-scale structures. Joints are not abundant, and no system is apparent, though a study of aerial photographs shows a roughly radial system of joints, well expressed in some places and lacking in others. Pegmatite dikes are common, especially along the inner contact. Most of them strike approximately tangent to the contact and dip outward about 45°. The joints filled by these dikes show no displacements.

Another less distinct set of joints trends approximately parallel to the contacts and is vertical. These joints were probably important in determining the drainage pattern in the north and northeast part of the area underlain by the Lakeview.

RELATIONS TO ADJACENT ROCKS

Omitting the post-Cretaceous sediments, the Lakeview is everywhere in contact with rocks older than itself. The margins of the body are marked by flow lines which approximately parallel the contact. Limited assimilation and small-scale stoping produced a few narrow hybrid zones, and the contact is thus gradational over a distance of several tens of yards.

The attitudes of the contacts are roughly reflected by flow lines and schistosity. Even these, however, cannot be determined accurately. Streaked inclusions of Green Valley tonalite in the Lakeview are abundant along the contact, the plane of streaking varying at least 5° on either side of the vertical. The schistosity of the metamorphics is approximately vertical, except in one body of schist on the northwest edge of the ring, where it dips 75° NW. Everywhere structures in the older rocks surrounding the ring are concordant with the contacts.

EMPLACEMENT

Forceful injection may have played some part in the emplacement as suggested by the concordant schist bodies and flow lines. Much of the distension must have been produced by the Green Valley tonalite, which may have been intruded as a boss. However, emplacement was probably not entirely by this process for this would necessitate large horizontal displacements. Furthermore, the boss would probably show flow lines or some other concentric features. Much of the concentric form of the schists may be due to a pre-existing domical structure in the prebatholith complex.

Piecemeal stoping in a cylindrical zone around the boss would have helped to provide space for the ring intrusion. Contacts could have remained smooth by stoping along concentric surfaces. However, the absence of large stoped inclusions in the ring dike is surprising if this process was extensive.

The circular distribution of the rocks strongly suggests ring-fracture stoping. The importantance of this depends upon the attitudes of the contacts which can be determined only approximately. Vertical contacts would not aid emplacement of the Lakeview tonalite since movement along such contacts would leave no gap for ring-dike intrusion.

If the contacts dip inward, a relative upward movement of the central mass would provide space for the intrusion of the ring dike. However, it seems unlikely that this took place as the central rock has appreciably higher specific gravity.

The hypothesis of outward-dipping contacts and concentric piece-meal stoping best explains the emplacement of the ring dike.

The following sequence of events is suggested. Prior to the formation of the late Mesozoic batholith, there existed a more or less concentric domical structure in the complex of schist and gneissoid intrusives. Into the center of this was intruded a boss of Green Valley tonalite, possibly by ring-fracture stoping, but in part by forceful injection, which may have perfected the circular structure. The Bonsall tonalite then either stoped away, or assimilated, the western part of the older complex. Next, the Lakeview tonalite ring was injected along a ring fracture formed around the Green Valley tonalite boss. Concentric piecemeal stoping aided the emplacement.

Obviously, the structure here described cannot be compared with ring-dike structures composed of shallow intrusions, such as those of Scotland, but it does not differ greatly from such ring dikes as those of the Mourne Mountains (Richey, 1928) or those in New England described by Kingsley (1931), Modell (1936), Chapman (1935; 1940), and others.

The most unusual feature of the Ramona structure is the concordant attitude of the older rocks. A similar case is that in North Arran (Tyrrell, 1928), where a complex, consisting of two granites, forms a circular, intrusive body concordantly surrounded by the Dalradian schists. Tyrrell suggested that the granites may represent the roots of a ring complex and were emplaced mainly by forceful injection.

Concentrically zoned circular bodies of granite in the Llano-Burnett region, Texas (Keppel, 1940), are likewise surrounded by concordant schists and gneisses. However, they differ from the structures here described in that the central granites are younger than the texturally dissimilar outer granites. According to Keppel, forceful injection and distension of the metamorphic rocks was the chief mode of emplacement.

GRANODIORITES

The granodiorites form one of the most variable groups of rocks in the area, but owing to the transitions from one type to another it is difficult to map separate members; all have been included in two groups, each of which possibly represents several intrusions.

The Woodson granodiorite was named by Larsen for Woodson Mountain in the southwest corner of the Ramona quadrangle. It is relatively uniform and forms a more clean-cut unit than the rest of the rocks of this group. Large areas of Woodson granodiorite have been mapped in the San Luis Rey quadrangle, and these masses extend into the Ramona quadrangle. In addition, there are smaller ones in the central portion of the quadrangle.

The remainder of the granodioritic rocks have been called the Wolford granodiorite. This formation was named by Larsen for Lake Wolford on the west-central edge of the Ramona quadrangle. The Wolford rocks are very heterogenous and form a complex of granodiorite, quartz monzonites, and metamorphics (chiefly quartzites or feldspathic quartzites). Streaking and intermixing of the two rocks form large hybrid areas.

Contacts between the granodiorites and other rocks are rarely seen. Exact age relations are, therefore, difficult to determine, although inclusions show them to be younger than the gabbro and the Green Vally tonalite. Larsen considered the granodiorites to be the youngest plutonics in the San Luis Rey quadrangle. It has been assumed that these relations apply in the Ramona area.

WOODSON GRANODIORITE

PETROGRAPHY

The Woodson granodiorite is medium- or coarse-grained, mostly massive, but in some places slightly gneissoid. Ferromagnesians amount to less than 10 per cent and are well distributed. The rock is light gray, due in part to the ferromagnesian minerals and in part to the gray feldspar. Dark, fine-grained inclusions are widespread but are nowhere as numerous or large as those of the tonalites.

The texture is essentially granitic, but some sections show fine, granular aggregates of minerals which may be interstitial to the larger grains. Not all the grain boundaries are sharp; many are sutured.

The typical rock consists of at least 30 per cent quartz. This mineral has undulatory extinction and is locally granulated.

Plagioclase (An_{28}) is the most abundant feldspar, making up 30 per cent of the type sample. Roughly rectangular crystals 2 to 5 mm. long show fine albite twinning. Oscillatory zoning is prominent, and occasional calcic zones have been replaced by saussurite. Some crystals are not concentrically zoned but have mottled extinction or include rectangular patches of a different composition. Small indeterminable inclusions are abundant, especially along cleavages, crystal boundaries, or twinning planes. These inclusions may indicate incipient weathering, although they are quite abundant in apparently fresh rocks.

TABLE 7.—*Analyses, mode and norm*

Analyst, F. A. Gonyer

ANALYSIS		NORM	
SiO_2	72.58	Q	32.10
TiO_2	.30	Or	16.68
Al_2O_3	14.12	Ab	33.01
Fe_2O_3	.65	An	12.23
FeO	2.36	Hy	3.50
MnO	.02	Mg	.93
MgO	.07	Il	.61
CaO	2.44		
Na_2O	3.91	MODE (Volume percentage)	
K_2O	2.84		
H_2O-	—	Plagioclase	52
H_2O+	.32	Quartz	30
P_2O_5	—	Hornblende	1
SO_3	.07	Biotite	3
ZrO	.05	Magnetite	1
	99.73	Orthoclase	12.5

Potash feldspars are represented by microcline and orthoclase, the latter forming perthitic intergrowths with albite. The proportion of albite in the perthites is unusually small and may vary up to 5 per cent. The microcline has the characteristic grid structure and occurs as small patches in the finer granular aggregates of quartz and feldspar, as well as in large, almost square crystals 3 to 4 mm. across.

Biotite is the chief ferromagnesian mineral but seldom exceeds 5 per cent. It forms shreds and foils and shows no systematic orientation in most samples, although, in some, a crude gneissic structure is produced.

Hornblende may be absent, but most sections show 1 to 2 per cent. It is commonly associated with biotite and magnetite as irregular, roughly prismatic grains. Alteration to chlorite along cleavage planes is typical. Sphene, zircon, and apatite are the usual accessories.

CHEMICAL COMPOSITION

The analysis (Table 7) kindly furnished by E. S. Larsen, is of a sample from the type locality on the south slope of Woodson Mountain, sec. 34, T. 13 S., R. 1 W. The norms are calculated from this analysis, and the mode taken from thin sections of the analysed rock. A noteworthy feature is the high silica content. This is characteristic of the granodiorites of the Peninsular Range. Iron, magnesia, and calcium are much lower than in the average granodiorite quoted by Daly (1933, p. 15).

ABNORMAL PHASE

Mount Gower, in the south-central part of the Ramona quadrangle, and Roderick Mountain in the northwest are composed largely of rocks similar to the Woodson and mapped as that formation. However, they differ microscopically from the type Woodson.

On the east slope of Mt. Gower, the granodiorite is distinctly porphyritic, with sparsely distributed squarish crystals of potash feldspar 1 to 2 cms. across. Occasional dikelets 1 to 5 cms. thick contain chiefly microcline, albite, and myrmekite.

The texture of these rocks is granitic in its broad features but is strikingly different in detail. The grain size is noticeably less uniform than that of the normal Woodson. Quartz, instead of being confined to large grains and aggregates, or filling wedge-shaped interstices between feldspars, occurs also as irregular, lobate, and vermiform masses partly imbedded in the feldspar. Myrmekitic intergrowths form a large part of many sections (Pl. 2, figs. 5 and 6). Wartlike masses of myrmekite lie along the edges of, and protrude into, large orthoclase crystals. Veinlets of albite fill irregular spaces, mostly between large crystals but also cutting through them, especially along the cleavages, and locally enlarge to form bulges of myrmekite. There is little to suggest cataclastic or protoclastic textures.

Orthoclase is more abundant than in most of the granodiorites, and, with the microcline, may be of sufficient quantity to make the rocks monzonites. The orthoclase is mostly in perthitic intergrowths and occurs in roughly rectangular crystals ranging up to 2 cms. The larger ones carry inclusions of quartz, plagioclase, hornblende, and biotite; some are cut by albite veinlets. The borders are indented by myrmekite.

Microcline occurs in smaller amount than perthite, but with much the same habit. Microcline perthite is rare.

There are at least three varieties of plagioclase, all sodic. Normal oligoclase is the earliest to crystallize, forming 1- to 2-mm. grains and tablets, finely twinned. There is 30 to 40 per cent of this plagioclase in the average section. A few crystals have calcic (An_{40}) cores which are either fresh or sericitized and saussuritized.

A second, more sodic plagioclase (An_{10-15}) forms most of the myrmekite. The proportion (70 to 90 per cent) and composition of plagioclase in the myrmekite are variable. No relation could be found between the ratio of plagioclase and quartz and the composition of the plagioclase. Some myrmekite masses have very little quartz at one end but much at the other, the latter usually extending into a potash feldspar crystal.

A third plagioclase (An_{5-10}) is a water-clear albite. It forms veinlets and rims around myrmekite masses. Usually there is a fairly sharp break between this and the inner plagioclase of the myrmekite.

Biotite is the chief ferromagnesian mineral, but there is never more than 5 per cent. It occurs as well-distributed, unoriented flakes 0.5 to 1 mm. long. Little or none is intimately associated with the myrmekite, and none in small shreads, or poikilitic flakes suggesting secondary origin. Streaks are altered to green chlorite.

Muscovite is always present, but only in small amount. Dark-green hornblende forms a small part of some sections. Accessories are sphene, zircon, magnetite and apatite.

Evidences strongly suggesting that migrating solutions were active in the Woodson granodiorite are: (1) albite vienlets in large microcline crystals; (2) roughly linear, chainlike distribution of myrmekite masses connected by albite veinlets; (3) dikelets of microcline, albite, and myrmekite. Vogt (1927 p. 496), Goldschmidt (1922, p. 6–7), and Bowen (1928, p. 132) have shown that such residual liquid would probably be soda-rich if there were a high water content in the magma which, by bringing about early separation of biotite, would lead to a suppression of potash feldspar in the low-temperature derivatives.

There is little indication of cataclastic structures; hence solutions must have moved largely along channels between crystals in the partly crystallized magma, or possibly formed in part by late magmatic movements.

Suggested events giving rise to the myrmekite rocks are: (1) nearly complete crystallization of a wet granodioritic magma; (2) confinement of soda-rich solutions to intercrystal spaces and possibly to fractures produced by late magmatic movements; (3) replacement of potash feldspar bordering these channels by plagioclase (approximately An_{10-15}); the result being an excess of quartz which, with albite, went to make up the myrmekite. Potash must have been almost entirely removed as there is little mica present, none of it secondary; (4) change of composition of circulating solutions which then precipitated clear albite (An_{5-10}) in veinlets and as rims around myrmekite.

WOLFORD GRANODIORITE

GENERAL CHARACTER

Despite the variability of rocks mapped in this group, certain distinctive characteristics are more or less uniform. Banding is common enough to be a fair criterion.

Texturally, the Wolford is finer-grained than the Woodson, the former being medium to fine even granular, nearly aplitic. Mineralogically, the Wolford is distinguished by its low percentage of dark minerals.

PETROGRAPHY

The texture is dominantly medium- to fine-grained and may be hypautomorphic granular but is more commonly aplitic. In some slides there is a "mosaic" texture (Miller, 1935, p. 141); in others it resembles hornfels texture.

Quartz, the chief mineral, constitutes at least half the average rock. It is usually free from inclusions and has sharp extinction. Microcline is generally more abundant than in the Woodson, occurring as rectangular grains, 2 mm. wide. Microcline microperthite is abundant, and perthitic intergrowths amount to 5 to 10 per cent. Plagioclase (An_{15-20}) is present in equant, sometimes zoned crystals with broad albite twinning bands. Myrmekite is sparse but widespread. While biotite is more abundant than muscovite, neither exceeds 3 per cent of most samples.

Magnetite is the chief accessory, but zircon and apatite occur.

Hypersthene is an important constituent of the Wolford just southeast of Lake Wolford. It makes up 5 to 10 per cent of the rock which thus may be called hypersthene granodiorite. The

mineral occurs mostly as isolated grains, but a few have hornblende rims. With this exception hornblende is absent, and biotite scarce. There is nothing to indicate assimilation of foreign material.

CHEMICAL COMPOSITION

The wide variations of rock types in this group make it impossible for any one chemical analysis to be representative; one (Table 8) is typical of only one phase.

TABLE 8.—*Analysis of Wolford granodiorite from a quarry in sec. 28, R. 1 W., T. 12 S.*
Analyst, F. A. Gonyer

ANALYSIS		NORM	
SiO_2	74.68	Q	38.10
TiO_2	.15	Or	11.68
Al_2O_3	13.80	Ab	34.58
Fe_2O_3	.79	An	10.29
FeO	1.13	Di	1.12
MnO	.03	Hy	1.69
MgO	.21	Mg	1.16
CaO	2.26	Il	.30
Na_2O	4.10	Ap	.33
K_2O	2.01		
H_2O-	.02	MODE (Volume percentages)	
H_2O+	.44		
P_2O_5	.09	Plagioclase	50
SO_3	—	Quartz	38
		Biotite	7
	99.71	Magnetite	0.5
		Orthoclase	2

This phase is relatively low in quartz and orthoclase and high in biotite. The plagioclase is relatively sodic. The analysis shows high SiO_2 and low lime and magnesia.

DIKES

Dikes cutting the Woodson and Wolford granodiorites are almost all aplites ranging from veinlets to dikes 2 to 5 feet thick and cropping out over several hundred feet. Their superior resistance to weathering causes them to stand out above the general level of the granodiorite, which may be completely weathered to a residual soil, leaving the aplites as rows of jointed blocks fitted together like a flagstone walk.

The average aplite is a pale, light-brown rock with a compact, even, fine-grained texture in most parts but locally grades from an aplitic border to a pegmatitic center. The texture is microgranitic rather than typically aplitic.

The aplites are composed of nearly 50 per cent quartz which occurs as small interstitial aggregates and as 0.5- to 1- mm. grains, exceeding the size of any other mineral in the rock. All grains have undulatory extinction. Microcline is the chief feldspar, although perthite is present as well as a very minor amount of plagioclase (approximately An_{20}).

Strongly pleochroic biotite up to 2 or 3 per cent, is the only ferromagnesian mineral. Magnetite is a fairly abundant accessory.

THEORETICAL CONSIDERATIONS

CHEMICAL RELATIONS

The oxides of the analyses given on preceding pages are plotted against silica in Figure 4. Disregarding a few exceptional points, fairly smooth curves can be drawn

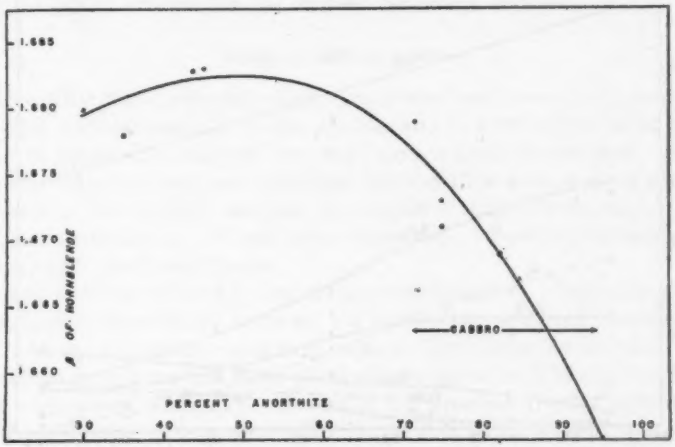

FIGURE 3.—*Graph showing relationship between composition of plagioclase and hornblende in gabbro and younger intrusive rocks*

showing the trend of the chemical composition of the intrusions in relation to time (since the silica values correspond approximately to the relative ages).

The curves follow the forms of those for the average plutonic series, but a few peculiarities may be pointed out. The alumina values form a nearly straight line with a slope which would be produced by increasing silica with a constant and absolute value for Al_2O_3. However, variations of other constituents probably complicate the relations. The steepness of the alumina curve is noteworthy.

The FeO and MgO curves show well the changing FeO/MgO ratio which is normal in that it increases with increase in silica. This change is also seen in the ferromagnesian minerals, especially hornblende (Fig. 3).

CAUSES OF DIVERSITY OF ROCK TYPES

This investigation has yielded little evidence on the origin of the instrusions. Innumerable difficulties confront each of the many theories commonly advanced to account for the diversity and sequence of intrusions.

Derivation of these rocks through fractional crystallization is suggested by the progressive mineralogical and chemical changes, particularly in the gabbros where the Fe/Mg ratio of the hornblende increases with silica. Other similar, but less marked, trends are shown by the variation diagram.

The acid type of the exposed rocks are far too abundant to have been derived by

differentiation from a primary basic magma. However, the proportions seen on the surface may not necessarily be those at depth.

Judging by the rocks now exposed, the intrusives encountered two main types of wall rock, the metamorphics and the older intrusives (Stonewall and/or members of

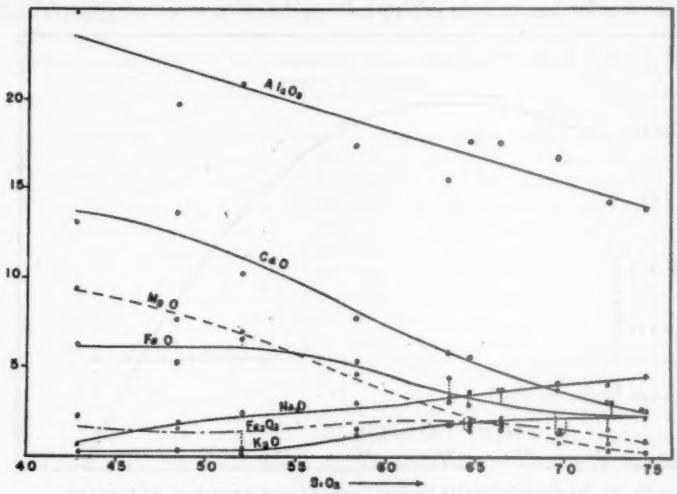

FIGURE 4.—*Variation diagram of the gabbros and younger intrusive rocks*

the batholith). The assimilation of metamorphics by the granodiorite is suggested by the extensive and intimate mechanical mixing along contacts, which are nearly always gradational. It is impossible to tell how much of the metamorphics have been chemically absorbed, or "digested", by the granodiorite, but the chemical composition of the rocks shows that the importance of the process is definitely limited. No analyses of the quartzites or schists are available, but according to Miller (1937, p. 1424) it may be assumed that they contain potash and soda in roughly equal amounts. An addition of sufficient foreign material of that composition to a gabbro magma to produce an increase of Na_2O from 0.76 in the olivine norite to 2.40 in the norite would cause an accompanying rise of K_2O far above that found in the analyses. Further assimilation of xenolithic material sufficient to give the potash values of the granodiorites would produce an excess of soda. Disregarding these difficulties, perhaps the high silica values of the granodiorite are the result of assimilation of quartz-rich metamorphics. However, if enough silica is subtracted from the analyses to give the value for this constituent in the average granodiorite, the other components have abnormal values, showing that those rocks could not be produced by the addition of silica to a typical granodiorite magma, unless other factors operated simultaneously.

The assimilation of older intrusives by younger is of most importance in the tonalites. These rocks, when intruded, encountered the widespread and earlier gabbro. Hurlbut (1935, p. 611) has suggested that perhaps some of the tonalite intrusions

occurred while the gabbro was only partially crystallized, thus facilitating mixing and assimilation.

Evidences that this assimilation was fairly important are: the widespread and locally abundant (up to 30 per cent) partly assimilated, dark inclusions in the tonalites; the calcic cores of plagioclase; and the gradational contacts or hybrid zones between the gabbro and tonalite and between the various tonalites.

MODE OF EMPLACEMENT

Stoping.—That this process was of some importance is indicated by the abundance of xenolithic material especially in the tonalites and to a less extent in the granodiorites. In almost all contacts of these rocks there is a wide shatter zone.

It may be argued that this zone represents only a small percentage of the apparent total volume of the batholith and that the absence of stoped blocks larger than a few feet long shows this to be of only minor importance. However, the large stoped blocks may have sunk much deeper.

A stronger objection is found in view of the contacts mapped. Ordinarily, stoping produces blocky, cross-cutting contacts, but in this area the lines of contact are smooth. Almost all parallel, rather than cross-cut, flow lines and schistosity. Perhaps marginal assimilation and minor piecemeal stoping of small blocks rounded off contacts which were once blocky. If some of the intrusives invaded rocks still in the crystal mesh state, as suggested by Hurlbut, smooth contacts might be expected. Large-scale stoping was suggested for rocks in the ring-dike structure but seems to be limited to that area.

Assimilation.—The tonalites and granodiorites show most evidence of assimilation. In the former, especially the Green Valley tonalite, the abundant calcic plagioclase cores and partly reworked pyroxenes point toward assimilation. The intimate field relations between the granodiorites and metamorphics suggest similar action. However, considering the relatively large areas of apparently uncontaminated rocks of these types showing no unusual minerals or textures, it seems unlikely that assimilation could have been responsible for the emplacement of more than a minor portion. It might be impossible to assess the amount of assimilation if reactions went on to completion.

Forceful injection.—Distension effects are shown by the nearly vertical dips and concordant strikes of the schist bodies throughout the area; no truly cross-cutting relations were seen. These structural relations are limited to the metamorphics and gneissoid Stonewall rocks. Whenever a late intrusive is in contact with an earlier intrusive (excepting the Stonewall) the earlier does not necessarily show structures or textures parallel to the contact. Thus forceful injection was apparently limited to the metamorphic rocks. The extent of the schists is not great, and their compression and distortion to conform to the intrusions would yield only a small percentage of the space required, unless there were extensive vertical displacements—that is, doming. There is no evidence for or against this action. The concordant contacts, however, do not prove whether the schists were distorted to fit the intrusives or the intrusions passively conformed to the pre-existing schist structure.

CONCLUSIONS

The uniformity of the gabbro, the lack of suggestion of appreciable contamination, the fact that it is the first intrusive of the series, and comparison with similar cases indicate that the gabbro was probably formed by direct crystallization of a primary magma of mafic composition. Its emplacement may have taken place by forcing aside older rocks, but also in part by stoping, the xenoliths sinking and being digested. Differentiation by crystal settling and perhaps volatile transfer occurring simultaneously with assimilation may have caused the magma to become progressively more felsic.

If, during the course of such assimilation and differentiation, periodic intrusive impulses occurred, there would be a series of intrusions of increasingly felsic composition. It is impossible to determine the relative importance of such deep-seated assimilation. If it were an important factor, the earlier intrusions should contain more partly reacted foreign material, unless it is supposed that crystallization occurred later, and the intrusive impulses caused merely a squeezing out of the interstitial liquid. The relatively large amount of acid intrusive suggests extensive assimilation of silicic material, although the proportions may be quite different at depth.

No one theory satisfactorily explains how the series of magmas attained their present positions. The evidence indicates a number of processes working together. Thus, stoping, assimilation, and forceful injection seem to be of almost equal importance, although locally one process may have dominated.

AGE OF THE INTRUSIVES

Field relations in the Ramona area show the batholithic rocks to be post-Triassic and pre-Eocene Tejon. Dudley (1935), Fraser (1931), Jenkins (1938), and others tentatively placed the intrusions in the Jurassic. Larsen (1945) assigned them to the middle Cretaceous. Similar intrusions in Lower California are reported as probably upper Cretaceous by Woodford and Harriss (1939).

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2249 Third Avenue, Sacramento, Calif.

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PLATE 2.—PHOTOMICROGRAPHS OF ROCKS FROM THE RAMONA QUADRANGLE

Figure

1.—Thin section of quartz-sillimanite schist with rutile granules, collected a mile southeast of Ramona. Plane polarized light, ×60.

2.—Thin sections of Stonewall quartz diorite from Volcan Mountain, showing distorted and crushed minerals. Crossed nicols, ×60.

3.—Photomicrograph of San Marcos gabbro, showing vermicular spinel intergrown with hornblende. Plane polarized light, ×60.

4.—Photomicrograph of Green Valley tonalite from Guejito. Crossed nicols, ×30.

5.—Photomicrograph of Woodson granodiorite from Mount Gower, showing albite veinlets along cleavage cracks and crystal boundaries of orthoclase. Crossed nicols, ×60.

6.—Photomicrograph of Woodson granodiorite from Mount Gower, showing myrmekite and albite veinlet in orthoclase. Crossed nicols, ×60.

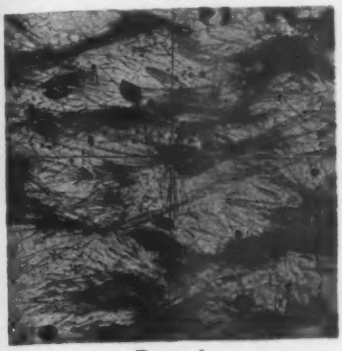


FIGURE 1

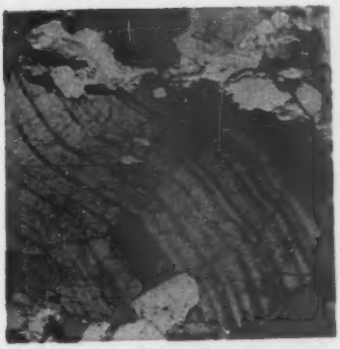


FIGURE 2

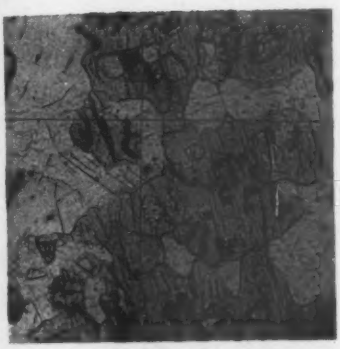


FIGURE 3

FIGURE 4

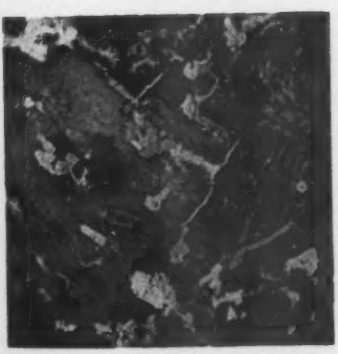


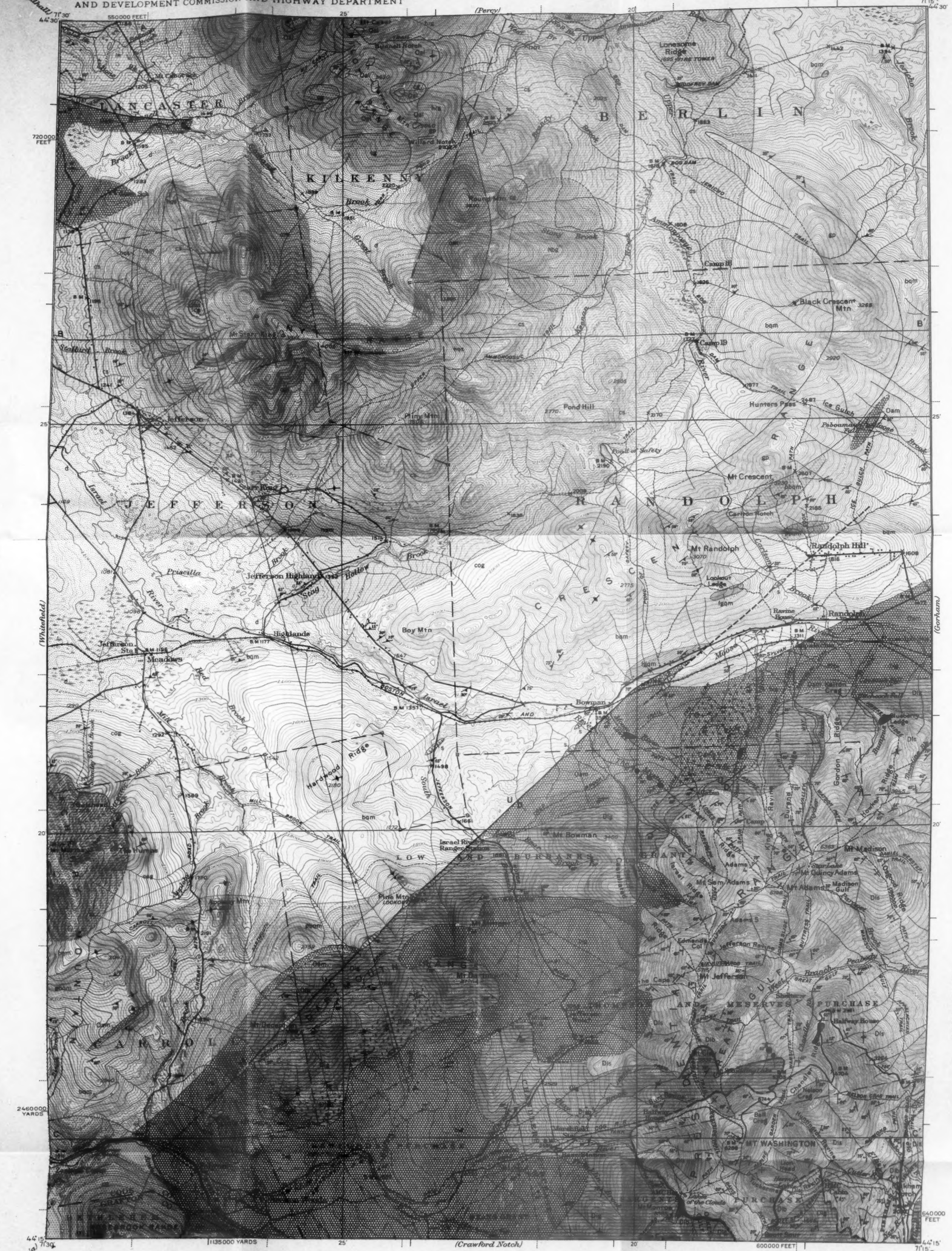
FIGURE 5

FIGURE 6

PHOTOMICROGRAPHS OF ROCKS FROM THE RAMONA QUADRANGLE

NEW HAMPSHIRE STATE PLANNING
AND DEVELOPMENT COMMISSION AND HIGHWAY DEPARTMENT

NEW HAMPSHIRE
MT. WASHINGTON QUADRANGLE


LANCASTER
KILKENNY
B E R L I N
J E F F E R S O N
R A N D O L P H
C R E S C E N T
P U R C H A S E
M T. W A S H I N G T O N
Lonesome Ridge
Burnell House
Mt Crescent
Mt Randolph
Randolph Hill
Carlton Notch
Jefferson Highlands
Highlands
Meadows
Boy Mtn
Pond Hill
Pliny Mtn
Hunters Pass
Ice Gulch
Black Crescent Mtn
Camp 19
Camp 18
Mt Bowman
Mt Madison
Mt Adams
Mt Jefferson
Mt Sam Adams
Mt Quincy Adams
Mt Starr King
Mt Waumbeck
Hardwood Ridge
Bowman
Randolph
Gorham
Whitefield
Franconia
Crawford Notch
North Conway
Israel River
Peboamauk Lake
Ammonoosuc
Upper Ammonoosuc
Moose
Mill
Stag
Hardwood
Ridge
Gordon
Ridge
Durand
Ridge
Adams
Ridge
Jefferson
Ravine
Edmands
Col
Chandler
Ridge
Huntington
Ravine
Ball
Crag
Nelson Crag
Trail
Carter Notch
Road
Base Line
Camp
Ravine
House
Halfway House
Glen House
Glen Station
Pinkham Notch
Cascade Brook
Ravine Brook
Bowman
AMC
Log Camp
Lodge of the Clouds
Lakes of the Clouds
Huntington
Ravine
Trail
Tuckerman
Ravine
Trail
Crescent
Ridge
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Jefferson
Ravine
Trail
Gulfside
Trail
Israel
Ridge
Trail
Randolph
Path
Link
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Randolph
Mt Club
Trail
Valley Way
Trail
Osgood
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Madison
Gulf
Trail
Air Line
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Daniel
Webster
Trail
Star
Lake
Trail
Parapet
Trail
Edmands
Path
Six
Husbands
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Watson
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Cutler
Ridge
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Cornice
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Alpine
Garden
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Pleasant
Road
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Washington
Auto
Road
Mt
Washington
Cog
Railway
Base
Station
Summit
House
Tip
Top
House
Fabyan
House
Fabyan
Station
Bretton
Woods
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Deception
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Eisenhower
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Monroe
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Franklin
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Madison
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Washington
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Starr
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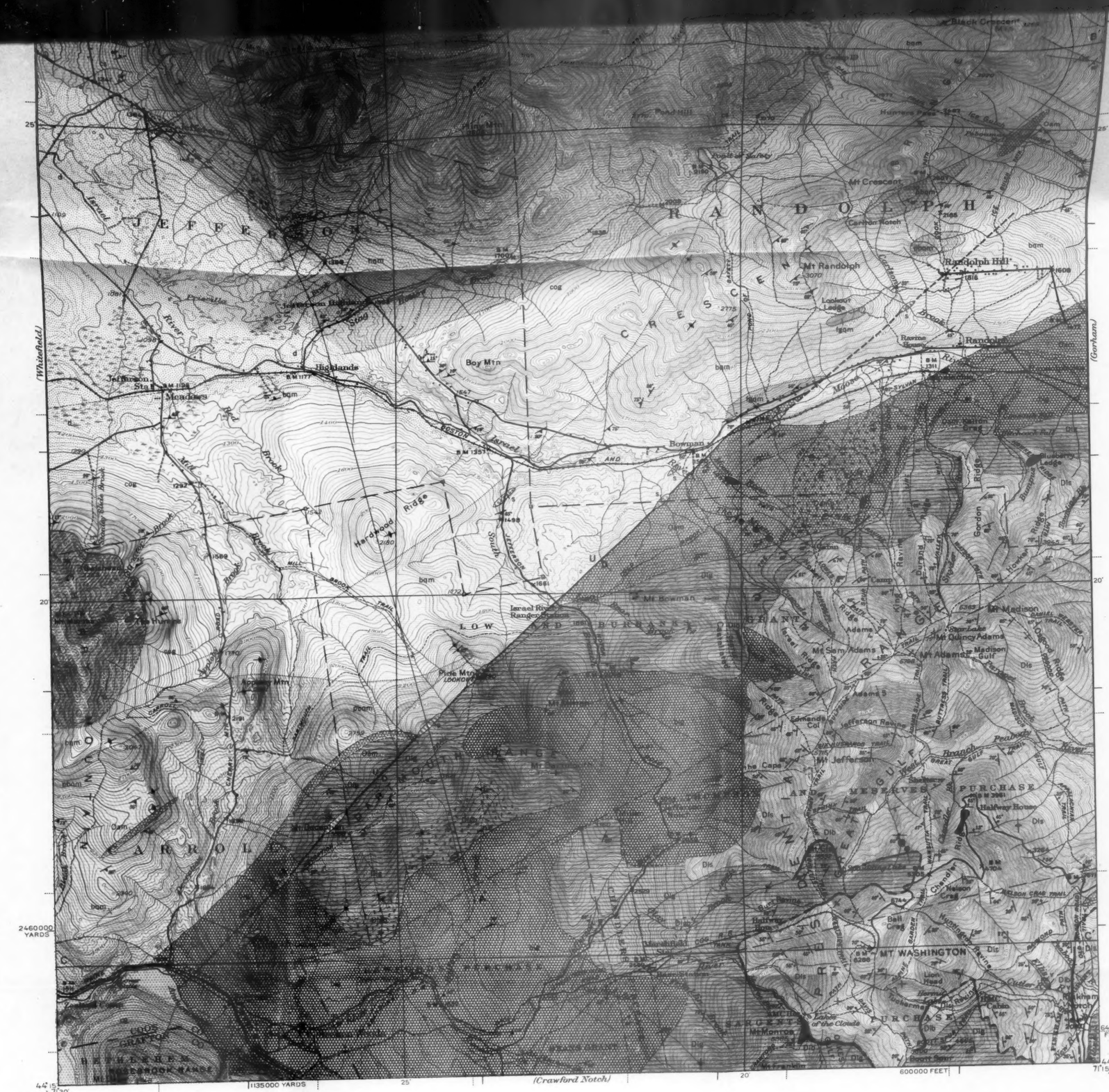

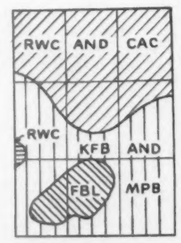

GEOLOGIC MAP AND STRUCTURE SECTIONS OF THE MT. WASHINGTON QUADRANGLE, NEW HAMPSHIRE

Topographic base by U. S. Geological Survey.

APPROXIMATE MEAN DECLINATION, 1935

Scale 1/62500

1 0 1 2 3 4 Miles
5000 0 5000 10000 15000 20000 Feet
1 0 1 2 3 4 5 Kilometers

Contour interval 20 feet

Datum is mean sea level

Geology by Marland P. Billings, R. W. Chapman, C. A. Chapman, Katharine Fowler-Billings, and F. B. Loomis, Jr., assisted by W. P. Fuller, Jr., and R. F. Storey.

Geology Surveyed 1936, 1938, 1939, 1940, with the aid of grants from the Associates in Science of Harvard University and the Penrose Bequest of the Geological Society of America.
Published 1945.

MISSISSIPPIAN ?
White Mountain Magma Series

LATE DEVONIAN ?
New Hampshire Magma Series

MIDDLE DEVONIAN ?
Oliverian Magma Series

PRE-SILURIAN ?
Sequence Uncertain

hgg — **Hastingsite-biotite granite**
(Fine-grained to medium-grained pink rock, composed of microperthite, quartz, oligoclase, hastingsite, and biotite.)

hrg — **Hastingsite-riebeckite granite**
(Medium-grained green granite, weathering white, buff, or pink, composed of microperthite, quartz, oligoclase, hastingsite, riebeckite, and a little biotite.)

hqs — **Hastingsite-quartz syenite**
(Subporphyritic, medium-grained, green quartz syenite, weathering white, pink, or brown, composed of microperthite, quartz, hastingsite, hedenbergite, and a little biotite.)

sy — **Syenite**
(Chiefly a fine-grained to coarse-grained green syenite, weathering buff to white, composed of microperthite, oligoclase, orthoclase, hedenbergite, and sodic hornblende; locally a quartz syenite.)

qm — **Quartz monsodiorite and quartz monzonite**
(Medium-grained to coarse-grained dark-gray rocks, composed of andesine, orthoclase, quartz, hornblende, biotite and magnetite.)

peg — **Pegmatite**
(Large, interlocking crystals of feldspar, quarts, biotite, muscovite; includes some granite.)

bg — **Bickford granite**
(Medium-grained to coarse-grained, locally porphyritic, white to gray binary granite composed of microcline, orthoclase, quartz, oligoclase, biotite and muscovite.)

pbqm — **Porphyritic biotite-quartz monzonite**
(Medium-grained, pink to gray foliated granular rock; phenocrysts of microcline, 5 to 15 mm. long, commonly composed of Carlsbad twins; groundmass consists of microcline, quartz, oligoclase, and some biotite and muscovite.)

bqm — **Biotite-quartz monzonite**
(Medium-grained, pink, foliated, granular rock, composed of microcline, quartz, oligoclase, and some biotite and muscovite.)

cog — **Coarse granite**
(Coarse-grained, pink rock, generally massive and only locally foliated, composed of microcline, quartz, oligoclase, and a little biotite, hornblende, and magnetite.)

cs — **Coarse syenite**
(Coarse-grained to medium-grained pink rock, generally foliated; composed chiefly of microcline that shows Carlsbad twins; groundmass composed of oligoclase, hornblende, biotite, and some magnetite.)

fgqm — **Fine-grained gray quartz monzonite**
(Fine-grained, gray, generally massive, locally foliated, rock, composed of oligoclase, quartz, microcline, biotite, and a little magnetite and muscovite.)

hqm — **Hornblende-quartz monzonite**
(Very variable rock; medium-grained to coarse-grained, porphyritic and non-porphyritic. In porphyritic type pink to white phenocrysts of microcline, composed of Carlsbad twins, are set in a dark-gray groundmass of oligoclase or andesine, microcline, quartz, hornblende, and biotite. In non-porphyritic type only the groundmass is present.)

Dsl — **Silver formation**
(Fine-grained light-gray to dark-gray quartzite, in bedded and foliated.)

BED ROCK NOT EXPOSED

d — **Glacial drift and alluvium**
(Shown only where exceptionally thick and extensive. No attempt has been made on this map to show the Quaternary deposits systematically.)

CONTACTS

Accurate

Approximate and diagrammatic due to poor exposures.

Indefinite as sharp contact is lacking

SPECIAL SYMBOLS

(Dip and strike symbols represent only a small percentage of the field observations.)

Strike and dip of bedding; in some cases represents general attitude of folded beds.

Strike of vertical beds

Strike and dip of overturned beds.

Horizontal beds.

Strike and dip of foliation of igneous rocks and gneiss.

Strike of vertical foliation of igneous rocks and gneiss.

Strike and dip of foliation parallel to axial plane of folds in Littleton formation.

Strike of vertical foliation parallel to axial plane of folds in Littleton formation.

Thrust fault; T on upthrown side.

Normal fault; D on downthrown side; U on upthrown side.

Silicified fault zone.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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GEOLOGY OF THE MT. WASHINGTON QUADRANGLE, NEW HAMPSHIRE

BY MARLAND P. BILLINGS, CARLETON A. CHAPMAN, RANDOLPH W. CHAPMAN, KATHARINE FOWLER-BILLINGS, AND FREDERIC B. LOOMIS, JR.

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ILLUSTRATIONS

Plate Facing page
1. Geologic map and structure sections of the Mt. Washington quadrangle, New Hampshire. 261

ABSTRACT

The Mt. Washington quadrangle contains the highest peaks in the northern part of the Appalachian Highlands. This paper presents a brief summary of the geology to accompany a colored geological map that has just been printed. The stratified rocks belong to three formations, the Ordovician (?) Albee formation, the Ordovician (?) Ammonoosuc volcanics, and the Devonian Littleton formation. All these rocks have undergone high-grade metamorphism, and such minerals as andalusite, sillimanite, staurolite, garnet, tourmaline, actinolite, and diopside are present. The intrusive rocks belong to four magma series, ranging in age from Late Ordovician (?) to Mississippian (?).

The structure of the whole quadrangle is dominated by a northeasterly trending dome, the center of which is occupied by the intrusive Oliverian magma series. The metamorphosed sedimentary and volcanic rocks on the flanks of this dome are thrown into countless folds, ranging from minor folds seen in single outcrops to larger folds hundreds and thousands of feet in wave length and amplitude. The folding is probably Acadian (middle to late Devonian). The intrusive rocks show a variety of structural forms. The Oliverian magma series apparently consists of a series of concordant lenses. The White Mountain magma series occurs in ring-dikes, stocks, and volcanic vents.

INTRODUCTION

The principal purpose of this paper is to present a colored geological map of the Mt. Washington quadrangle, New Hampshire (Pl. 1). The map is accompanied by three structure sections and a relatively detailed legend. The printing of the colored geological map has been delayed for several years, chiefly due to the war. It seemed inadvisable to delay publication of the scientific papers, and most of the information has already appeared in a series of publications by R. W. Chapman (1937; 1942), Billings (1941), Chapman, Billings, and Chapman (1944), and Fowler-Billings (1944a). The most recent paper on the physiographic and glacial geology is by R. P. Goldthwait (1940). With the appearance of this colored geological map, many readers not specialists in petrography and metamorphism may welcome a brief summary of the geology of a typical New Hampshire quadrangle. Finally, the issuance of this map presents an opportunity to record some modifications of and additions to the earlier publications.

The study of the bedrock geology was financed in part by grants from the Penrose Bequest of The Geological Society of America and The Associates in Science of Harvard University. The funds for publishing the colored gelogical map (Pl. 1) were supplied by the State Planning and Development Commission and the Highway Department of New Hampshire.

TOPOGRAPHY AND DRAINAGE

Mt. Washington is the highest point in the northern part of the Appalachian Highlands. A glance at Plate 1 emphasizes the rather nondescript character of the topography, the mountains and valleys displaying no obvious pattern. This is characteristic of much of New Hampshire.

The total relief in the Mt. Washington quadrangle is 5250 feet. The Presidential Range, in the southeast part of the quadrangle (Pl. 1), is convex toward the northwest and contains Mt. Washington (6288 feet), Mt. Jefferson (5715 feet), Mt. Adams (5798 feet), and Mt. Madison (5363 feet). The Dartmouth Range in the south-central part of the quadrangle trends northeasterly, and the highest summit is Mt. Dartmouth (3721 feet). Mt. Oscar (2748 feet), in the extreme southwest corner of the quadrangle, is at the northwest end of the Rosebrook Range. Cherry Mountain, the summit of which is called Mt. Martha (3554 feet), lies along the western margin of the quadrangle. The Crescent Range sweeps northeasterly in a broad arc from the center of the quadrangle, reaching its highest elevation in Black Crescent Mountain (3265 feet). The southern end of the Pilot Range occupies the north-central

part of the Mt. Washington quadrangle; the highest point in this range, Mt. Cabot (4080 feet), lies in the adjacent Percy quadrangle. The arcuate Pliny Range, just to the south of the Pilot Range, is convex toward the south; the highest point is Mt. Waumbek (4005 feet).

Most of the quadrangle drains westward to the Connecticut River by means of the Ammonoosuc, Israel, and Upper Ammonoosuc Rivers. A narrow belt a few miles wide on the east side of the quadrangle drains easterly through tributaries of the Saco and Androscoggin rivers to the Gulf of Maine.

LITHOLOGY

GENERAL STATEMENT

The stratified rocks of the Mt. Washington quadrangle have been assigned to three stratigraphic units, the Ordovician (?) Albee formation, the Ordovician (?) Ammonoosuc volcanics, and the Devonian Littleton formation. The metamorphism is high grade, and such minerals as andalusite, sillimanite, garnet, staurolite, mica, tourmaline, actinolite, and diopside are present. The igneous rocks, all of which are intrusive, have been assigned to four magma series: Highlandcroft (late Ordovician ?), Oliverian (middle Devonian ?), New Hampshire (late Devonian ?), and White Mountain (Mississippian ?).

ALBEE FORMATION

The Albee formation, confined to small areas in the northwestern part of the quadrangle, consists of fine-grained, light-gray to dark-gray quartzite. It is tentatively assigned to the upper Ordovician (Billings, 1937, p. 475; Kruger, 1946, p. 175–178).

AMMONOOSUC VOLCANICS

The Ammonoosuc volcanics of the Mt. Washington quadrangle consist chiefly of fine-grained biotite gneiss, with relatively small amounts of amphibolite, lime-silicate granulite, quartz-muscovite-pyrite schist, and mica schist. The original rocks were chiefly volcanic tuffs and breccias, although some flows may have been present. Before metamorphism the fine-grained biotite gneisses were soda rhyolite, the amphibolites and lime-silicate granulites were basalt and andesite. The quartz-muscovite-pyrite schist was argillaceous sandstone, and the mica schist was shale. The proof that the formation was in large part originally pyroclastic is found in the less metamorphosed rocks of the Littleton and Moosilauke quadrangles (Billings, 1937, p. 475–480). The Ammonoosuc volcanics in the Mt. Washington quadrangle attain a maximum thickness of 5000 feet; the base, however, is not exposed, because of the intrusive relations of the Oliverian magma series. The Ammonoosuc volcanics have been tentatively assigned to the upper Ordovician (Billings, 1937; Kruger, 1946, p. 175–178).

LITTLETON FORMATION

In the Mt. Washington quadrangle the Littleton formation has been divided into three mappable units. The lower part of the formation is gneiss composed of alter-

nating 1-inch dark and light layers; the dark layers are chiefly biotite, oligoclase, quartz, and muscovite; the light layers are chiefly oligoclase and quartz (Billings, 1941, Pl. 5, fig. 5). This rock is not an injection gneiss in the sense that light-colored granitic layers have been injected into layers of mica schist. Solutions moving through the original shales caused selective solution of the more soluble minerals. The liquids so generated gathered into irregular light-colored streaks. Although these light-colored layers constitute 50 per cent of the rock, the amount of material added, chiefly potash and soda, is not more than 1 to 5 per cent of the rock (Billings, 1941, p. 931).

It is not uncommon to find within the gneiss isolated blocks of totally different aspect. A description of these blocks was contained in the first draft of the original manuscript (Billings, 1941) but later was unfortunately eliminated in order to shorten the paper. In plan some of the blocks are angular, more or less rectangular; others are elliptical. The angular blocks, which range in length from a few inches to a maximum of 10 feet, consist principally of quartz, with small amounts of mica and garnet. Some of these blocks, particularly the larger ones, show bedding that is sharply truncated by the gneiss at either end. Such blocks are apparently fragments of beds which, because they were relatively brittle, have been broken up, pulled apart, and isolated from one another. Billings (1928, Fig. 3, p. 85) has described similar blocks in mica schist in the North Conway quadrangle.

Many of the elliptical blocks—presumably ellipsoidal in three dimensions—range from 6 inches to 3 feet in length and consist of such minerals as quartz, garnet, amphibole, diopside, sphene, and calcic plagioclase. One mode has been published, but no mention of it was made in the text (Billings, 1941, p. 894, mode 12). Some of these blocks are concentrically zoned. These blocks are metamorphosed concretions, similar to those described from high-grade schists in the Moosilauke quadrangle (Billings and Cleaves, 1935; Billings, 1937, p. 493). The original concretions are believed to have been dolomitic, because of the presence of minerals containing lime and magnesia. Pettijohn (1940) has described similar metamorphosed concretions in the pre-Cambrian of Canada.

The upper part of the Littleton formation, originally consisting of interbedded sandstone and shale, is now composed of quartzite and schist. Although the quartzites are relatively uniform throughout the area, the schists differ considerably because of variations in mineralogy, grain size, and intensity of the schistosity (Billings, 1941, Fig. 3 p. 888). Andalusite was formed rather early in the paragenesis (Billings, 1941, p. 921–923, Fig. 10). This was followed by sillimanite and garnet, and still later by staurolite and tourmaline. Muscovite, biotite, and quartz apparently formed throughout all these stages. Sericite and chlorite are late minerals, formed under relatively low-temperature conditions.

A new name, the Boott member, is here applied to a distinctive group of beds that lies about 1400 feet above the base of the Littleton formation. The name comes from Boott Spur, 1.2 miles south-southeast of the summit of Mt. Washington. The Boott member is exposed in a narrow belt extending north-northeast from the Boott Spur Trail to within a few hundred feet of Cutler River in Tuckerman Ravine. A small valley along the contact of the gneiss and schist south of Boott Spur is undoubtedly

underlain by this member, although no outcrops have been found. The Boott member is also well exposed on the headwall of Oakes Gulf and between altitudes 1620 to 1635 feet on the West Branch of the Peabody River; the latter locality is in the Gorham quadrangle. Although these places would perhaps have been better type localities, these names are preoccupied (Wilmarth, 1938, p. 1525, 1618).

The Boott member consists of diopside granulite, diopside-actinolite granulite, actinolite granulite, actinolite-biotite schist, biotite schist, and biotite-pyrite schist. The rocks containing actinolite and diopside were derived from dolomitic rocks. The maximum measured thickness of the Boott member in the Mt. Washington quadrangle is 65 feet, but between altitude 1620 and 1635 feet on the West Branch of the Peabody River a thickness of 136 feet is exposed (Billings, 1941, Table 4, p. 884).

The Boott member is almost exclusively confined to the southeast corner of the Mt. Washington quadrangle in a rectangle bounded on the west by longitude 71° 20′ W., and on the north by an east-west line passing through Mt. Clay. However, a small exposure has been observed a few hundred feet west of Cascade Brook, a mile southeast of Mt. Bowman. The Boott member has not been observed on the northern flanks of the Presidential Range.

In general the Littleton formation beneath the Boott member consists of gneiss, whereas above the Boott member it consists of interbedded quartzite and schists. As shown diagrammatically in the legend on Plate 1, the contact between the gneisses and the interbedded schists and quartzites does not everywhere correspond with the Boott member. In other words, gneisses locally occur above the Boott member, and quartzites and schists locally appear beneath the Boott member. Moreover, within the areas mapped as gneiss (*Dlg*) on Plate 1, there are belts of quartzite and schist, similar to the rocks composing the upper part of the formation, but too small to distinguish on the scale employed. Conversely, in the areas mapped as schist and quartzite (*Dls*) on Plate 1, there are bodies of gneiss that are too small to map separately.

The lower part of Littleton formation is 1400± feet thick on the northern flanks of the Presidential Range. The Boott member, locally absent at the appropriate horizon, reaches a maximum thickness of 65 feet. The upper part of the formation is 4000± feet thick.

In previous papers (Billings, 1941; Fowler-Billings, 1944a) the Boott member was correlated with the middle Silurian Fitch formation. Throughout most of the field work, however, the interpretation adopted on Plate 1 was the one favored. As pointed out previously (Billings, 1941, p. 899), attempts to trace formations from the type localities in the Littleton-Moosilauke area to the Mt. Washington quadrangle were frustrated by extensive igneous intrusions in the southwestern part of the Mt. Washington quadrangle. These intrusions eliminate the stratified rocks (Pl. 1). It was therefore necessary to correlate by lithologic similarity and matching similar sequences.

In the fossiliferous rocks at the type locality in Littleton (Billings, 1937, p. 483–486) the Fitch formation consists chiefly of (a) limestone, (b) calcareous slate, (c) sandstone, (d) dolomitic slate, and (e) dolomitic limestone. Toward the southeast, because of increasing metamorphism, the formation consists chiefly of the following

equivalent types: (a) marble, (b) mica-calcite schist, (c) quartzite, (d) actinolite-biotite schist, and (e) actinolite-calcite schist and actinolite-diopside granulite.

The granulites, containing actinolite, diopside, and magnesia-rich biotite, constitute a very small part of the lithology of New Hampshire. Billings (1941) correlated the Boott member, because it consists chiefly of lime-silicate rocks, with the Fitch formation of the type locality. Moreover, such a correlation seemed to be corroborated by the lithologic sequence. The rocks above the Ammonoosuc volcanics and beneath the lime-silicate rocks, chiefly gneisses, were correlated with the Partridge formation of the type locality (Billings, 1941, p. 899–902).

There are several reasons for changing the correlation. (1) it is now realized that lime-silicate rocks are not confined to the Fitch formation but occur as thin beds in several other formations. Thin beds were found in the Littleton formation in the Moosilauke quadrangle (Billings, unpublished data) and in the Plymouth quadrangle (Williams and Billings, 1938, p. 1017). They are even more extensively developed in the Littleton formation in the Bellows Falls quadrangle (Kruger, 1946) and Monadnock quadrangle (Fowler-Billings, 1944 b). Moreover, lime-silicate granulites occur in the Ammonoosuc volcanics in the Mt. Washington quadrangle (Billings, 1941 p. 875–876). It is now obvious that lime-silicate rocks in themselves have little value as a means of correlation.

(2) The Fitch formation in western New Hampshire contains considerable limestone, which is marble wherever the formation has been more thoroughly metamorphosed. The lime-silicate rocks of the Mt. Washington quadrangle have no marble associated with them. This suggests, although it is by no means a compelling argument, that the lime-silicate rocks of the Mt. Washington quadrangle do not belong to the Fitch formation.

(3) There are several facts indicating that the gneisses, schists, and quartzites above the Ammonoosuc volcanics and beneath the Boott member should be assigned to the Littleton formation rather than to the Partridge formation. The lime-silicate concretions found in these rocks are know to occur in the Littleton formation elsewhere (Billings, 1937, p. 493); they have not been observed in the Partridge formation. Occasional thin pink beds composed of garnet, quartz, and apatite have been found in the rocks above and below the Boott member. Such pink beds have been found elsewhere in the Littleton formation (Billings, unpublished data; Hadley, 1942, p. 133–134) but never in the Partridge formation.

Thus, although fossils are lacking in the Mt. Washington quadrangle and the formations cannot be traced back to the type localities, by means of lithologic similarity and sequence of lithologic types the gneisses above the Ammonoosuc volcanics and beneath the Boott member are correlated with the lower part of the Littleton formation, and the Boott member is part of the Littleton formation.

The Littleton formation has been classed as lower Devonian, on the basis of Oriskany fossils found 2500 feet above the base of the formation at the type locality in the Littleton quadrangle (Billings, 1937, p. 494). It is quite possible, of course, that the lower part of the formation is older than Oriskany, and the upper part may be younger.

HIGHLANDCROFT MAGMA SERIES

Mafic rocks in the northwest corner of the Mt. Washington quadrangle have been correlated with the Lost Nation group, the type locality for which is a few miles to the north in the Percy quadrangle (R. W. Chapman, 1935, p. 405). This group consists of medium-grained rocks, chiefly diorite and quartz diorite, but includes some gabbro and syenite. All the rocks show considerable hydrothermal alteration. The Lost Nation group belongs to the Highlandcroft magma series, which is believed to be late Ordovician (Billings, 1937, p. 499–500).

OLIVERIAN MAGMA SERIES

Rocks belonging to the Oliverian magma series, shown on the accompanying map (Pl. 1) in shades of green, occupy a large part of the area, and six units have been mapped: hornblende-quartz monzonite, fine-grained gray quartz monzonite, coarse syenite, coarse granite, biotite-quartz monzonite, and porphyritic biotite-quartz monzonite. These rocks are composed chiefly of potash feldspar, plagioclase, and quartz, with subordinate biotite, hornblende, magnetite, and accessories. Further details are given in the legend accompanying Plate 1, and more complete data have been presented by Chapman, Billings, and Chapman (1944). Chemical analyses of these rocks will be given in a forthcoming publication. The pink color of the potash feldspar imparts to many of the rocks in this magma series a characteristic pink shade. The boundaries between the various units are not sharp and consequently are shown on the geological map (Pl. 1) by dotted lines. Foliation, which is common, is believed to be partly primary but was utilized for later movements. The abundance of granoblastic textures indicates that the rocks have undergone considerable post-consolidation deformation.

NEW HAMPSHIRE MAGMA SERIES

The New Hampshire magma series is represented in the Mt. Washington quadrangle by the Bickford granite and some small bodies of pegmatite. The Bickford granite is a medium-grained to coarse-grained gray massive rock composed of potash feldspar, oligoclase, quartz, biotite, and muscovite. It occupies a large body extending from Bretton Woods northeasterly to Castle Brook, and a small body near Randolph station. The older rocks surrounding these two bodies are in places extensively injected by sills and dikes of Bickford granite. This is notably true of the southern flanks of the Dartmouth Range and between Cold Brook and The Link. An overprint of red hachures shows these areas (labelled *Dlgb* and *Oamb* on Pl. 1). The Bickford granite, although characteristically massive, locally displays a weak foliation, the attitude of which is shown on Plate 1 by appropriate symbols. This granite is the youngest member of the New Hampshire magma series and is tentatively assigned to the late Devonian.

WHITE MOUNTAIN MAGMA SERIES

The Mississippian (?) White Mountain magma series is extensively developed in the Mt. Washington quadrangle. It is abundant in the Pilot Range, Pliny Range,

Crescent Range, Cherry Mountain, and Rosebrook Range; moreover, small volcanic vents are exposed on the southeast corner of the quadrangle. The rocks belonging to this magma series have been mapped on Plate 1 as quartz monzodiorite and quartz monzonite, syenite, hastingsite-quartz syenite, hastingsite-riebeckite granite, hastingsite-biotite granite, granite porphyry, Conway granite (biotite granite), and volcanic vents. Detailed mineralogical descriptions are given in the legend accompanying Plate 1, and more complete data have been presented by R. W. Chapman (1937, 1942) and Fowler-Billings (1944a).

Three volcanic vents are shown in the southeast corner of the quadrangle. A fourth, exposed on the Cutler River 100 feet southeast of the Boott member, is too small to map. The vents consist in part of massive metadiabase, in part of breccias. The fragments of the breccias are angular to round blocks, a few inches to several feet across, composed of metadiabase, porphyritic basalt, kersantite, and vein quartz. Although in some localities the matrix of the breccias is metadiabase, more commonly it is a fine-grained tuff composed chiefly of feldspar, quartz, and mica. This tuffaceous matrix has been derived from the country rock that surrounds the vents. Details are given in a paper by Fowler-Billings (1944a, p. 1267–1268).

DIKE ROCKS

The dike rocks are not shown on Plate 1, but they have been described in detail by Fowler-Billings (1944a). One hundred and twenty-two dikes were observed and constitute only 0.05–0.1 per cent of the bedrock. The largest dike, a porphyritic metadiabase, 60 feet wide at maximum, extends north from 1.7 miles south-southeast of Mt. Martha (summit of Cherry Mountain) for 7.8 miles, to a point 0.5 mile northwest of the village of Jefferson. The igneous dikes, which average 5 feet wide, are chiefly metadiabase, camptonite, and kersantite; these varieties are late members of the White Mountain magma series. Of particular interest are dikes composed of actinolite-biotite granulite. Dolomitic shales from the Boott member of the Littleton formation were forced into cracks in a solid but highly plastic condition; they are now lime-silicate granulites.

STRUCTURAL GEOLOGY

GENERAL STATEMENT

The structure of the Mt. Washington quadrangle is typical of New Hampshire. Folded and metamorphosed sedimentary and volcanic rocks have been intruded by igneous rocks belonging to four successive magma series.

JEFFERSON DOME

The structure of the whole quadrangle is dominated by the Jefferson dome, a large anticline, the axis of which trends northeast from Cherry Mountain across Boy Mountain to a point east of Black Crescent Mountain. Structure section AA′ indicates the importance of this anticline.

The core of the anticline is occupied by intrusive rocks belonging to the Oliverian magma series. It is the foliation of these rocks that shows the anticlinal structure. The foliation is primary, although it has been utilized for later movements that have

produced a granoblastic texture in the rocks and have locally developed lineation. In general the crest of the anticline may be located by studying the foliation symbols on the geological map. Whereas the foliation 0.5 mile west of Boy Mountain dips 10°–30° NW., a mile south of Boy Mountain it dips 16°–30° SE. North and east of Cherry Mountain the foliation dips 10°–60° NW. Although there is some distortion of the foliation around the syenite body on Cherry Mountain, south and southeast of Cherry Mountain the foliation is generally vertical, because the rocks here are located on the vertical southeast limb of the anticline. The rocks on Mt. Randolph, and those east of Mt. Crescent and Black Crescent Mountain, lie on the southeast flank of the anticline, dips ranging from 45° to 85° SE. The anticlinal crest must pass though Black Crescent Mountain, because a mile southeast of the summit the foliation dips 55°–60° SE, whereas a mile to the north it dips 40° N. It is obvious, however, that many minor folds are superimposed on the major anticline, as the value of the dip of the foliation locally differs considerably within short distances.

The older sedimentary and volcanic rocks into which the Oliverian magma series has been intruded are found on both flanks of the anticline. On the northern slopes of the Presidential Range, between Mt. Bowman and the east edge of the quadrangle, the Oliverian magma series is overlain concordantly by the southeasterly dipping Ammonoosuc volcanics and the Littleton formation. In Lancaster township, in the northwestern corner of the quadrangle, the northerly dipping Ammonoosuc volcanics lie on the northern flank of the anticline (section AA′).

The various units of the Oliverian magma series were forcefully injected as concordant lenses into the Ammonoosuc volcanics (Chapman, Billings, and Chapman, 1944, p. 513). The domical structure of the Oliverian magma series is undoubtedly in part original, inherited from the time the magma was intruded into the horizontal Ammonoosuc volcanics. The dome was undoubtedly accentuated by later folding. It is impossible, however, to evaluate the relative importance of the two processes.

PRESIDENTIAL AND DARTMOUTH RANGES

The southeastern part of the quadrangle, including the Dartmouth and Presidential Ranges, lies on the southeast flank of the Jefferson dome. Minor folds, the wave length and amplitude of which are measured in feet or tens of feet, are locally conspicuous (Billings, 1941, Pl. 7). The larger folds, the wave length of which is measured in hundreds or thousands of feet, are inferred by the following means: (1) plotting the attitude of bedding; (2) the map pattern of the Boott member; (3) plotting the attitude of minor folds; (4) relation of bedding to axial plane foliation.

Bedding in the Boott member and in the interbedded quartzites and schists of the upper part of the Littleton formation is conspicuous in many areas (Billing, 1941, Pl. 5, fig. 3). Half a mile southwest of Pinkham Notch a syncline is shown by the dip-strike symbol for bedding. The east flank dips 20°–75° W.; the west flank dips 30°–66° E.

The bedding symbols in the vicinity of structure section CC′ also indicate the geological structure.[1] Countless minor folds, however, are superimposed on the major

[1] In structure section CC′ strata labelled *Dlg* at the extreme east end of the section should be labelled *Dls* and should have the pattern and color for *Dls*.

structure. A broad anticline plunging north is apparent near the Halfway House on the Auto Road, but in many parts of the area the minor folds are so numerous and of such magnitude that it is difficult, or even impossible, to determine the structure by merely noting the attitude of the bedding.

It is a well known principle that the map pattern of key horizons is extremely useful in deducing the geological structure, (Billings, 1942, p. 62). The Boott member is useful in this way, but because of the high relief the map pattern differs somewhat from that to be expected in a region of low relief.

The method of recording the attitude of minor folds and their use in deducing the geological structure has been discussed in a previous paper (Billings, 1941, p. 901–907). The attitude of the minor folds has not been shown on Plate 1, partly because it would complicate the map with too many symbols, and partly because of the expense in engraving the maps.

Two types of foliation occur in the schists in the upper part of the Littleton formation. The older one, parallel to the bedding, is not shown on Plate 1. A younger foliation, parallel to the axial plane of the folds, is shown by a special symbol with an open triangle.

The foliation in the gneisses in the lower part of the Littleton formation is apparently parallel to the original bedding and is shown by a special symbol with solid triangles on Plate 1. It is difficult to determine the location and size of the larger folds in the gneisses of the Littleton formation, and the folds shown on the Dartmouth Range in structure section AA′ are diagrammatic.

The folding is probably middle or late Devonian (Billings, 1941, p. 918–919).

BICKFORD GRANITE

The two stocks of Bickford granite, the larger of which extends northeasterly from Bretton Woods to Castle Brook, the smaller of which lies in the vicinity of Randolph Station, present a problem in the mechanics of intrusion. Some facts suggest stoping, notably the irregular pattern of the contacts and the manner in which formations appear to have been eliminated. For example, west of Randolph Station the Ammonoosuc volcanics have been almost completely removed by the Bickford granite. In Castle Brook, 2 miles northwest of Mt. Jefferson, part of the schists of the Littleton formation has been removed. The manner in which the surrounding country rocks are locally cut by numerous dikes and sills of Bickford granite indicate conditions favorable for isolating blocks of country rock as a preliminary to stoping. On the other hand, inclusions of older rocks are rare in the Bickford granite. Moreover, there is some evidence that the larger stock has wedged apart the older rocks, for in the Dartmouth Range the gneisses of the Littleton formation trend northeast, whereas in the southern part of the Presidential Range the trends are north–south. It was concluded (Billings, 1941, p. 918) that the Bickford granite forced its way into the older brittle rocks. The rocks surrounding the rising magma were mechanically shattered and broken, and countless dikes and sills were forced into the fractures. Blocks of country rocks were engulfed by the magma and sank, but the relative importance of forceful injection and stoping cannot be evaluated at present.

WHITE MOUNTAIN MAGMA SERIES

The White Mountain magma series in the Mt. Washington quadrangle is characterized by ring-dikes, stocks, volcanic vents, and dikes. R. W. Chapman (1942) has described the ring-dikes and stocks. One of the most striking circular structures is the ring-dike composed of granite porphyry in the Crescent Range. Another large ring-dike in the Pliny Range is composed of hastingsite-quartz syenite. On the western slope of the Pliny Range there is a composite ring-dike, the eastern part composed of quartz monzonite, the western part composed of hastingsite-quartz syenite. The contacts of the ring-dikes, although rarely observed, appear to be steep or vertical, for they cross areas of considerable relief without any apparent control. The arcuate "shatter zone", 2 miles south and southwest of the summit of the Pliny Range, consists of dikes of pink biotite granite, a phase of the Conway granite, cutting the coarse syenite of the Oliverian magma series. Northeast of the village of Jefferson the dikes of biotite granite carry inclusions of quartz monzodiorite.

The origin of the ring-dikes of New Hampshire has been discussed in numerous previous papers. There is complete agreement that the igneous rock is intruded along an arcuate fracture or fracture zone that is vertical or dips steeply outward. Because a down-faulted block of Moat volcanics is found inside each ring-dike composed of Albany quartz syenite (Billings, 1945, p. 47), New Hampshire geologists accepted the idea that all ring-dikes were associated with a down-faulted central block. In the Mt. Washington quadrangle and the Percy quadrangle to the north there is no direct stratigraphic or structural evidence that a central block has subsided. Moreover, as Billings (1945, p. 52) has suggested, the arcuate fracture could result from upward magmatic pressure.

The "shatter zone" southwest of the Pliny Range suggests one way that ring-dikes may form. An arcuate fracture zone, many hundreds of feet thick, is injected by magma. If sufficient time elapses, the fracture zone may be cleansed of all the older rocks, either by piecemeal stoping and sinking of the small blocks or by extrusion of the blocks along with the magma. This method has been advocated by Williams and Billings (1938, p. 1041) for some ring-dikes.

R. W. Chapman (1942, p. 1564) believes that the Crescent Range ring-dike was intruded into a circular or slightly elliptical fracture that encompassed 360 degrees. Subsidence of a central block that dropped downward and toward the west (Billings, 1942, p. 287) would leave a potential cavity on the east, and into this space the granite porphyry magma was intruded.

The principal stocks of the White Mountain magma series in the Mt. Washington quadrangle are: (1) stock of hastingsite-riebeckite granite in the Pilot Range; (2) syenite stock on Cherry Mountain; (3) stock of Conway granite in the southwest corner of the quadrangle. These stocks are believed to have been intruded by some stoping mechanism, chiefly the subsidence of large circular blocks (Billings, 1945, p. 54–55). However, the abundance of inclusions of the Albee formation in the Pilot Range indicates that piecemeal stoping also played an important rôle in the intrusion of this stock.

FAULTS

The most conspicuous fault in the quadrangle is the Pine Peak fault.[2] This fault can be traced readily from the west end of the Dartmouth Range to the vicinity of Bowman, and apparently extends at least as far as Randolph Hill. The fault is marked by silicified zones shown on Plate 1 by a special color pattern. The most conspicuous of these zones is on Pine Peak (Pine Mountain), the gleaming white ledges of which can be seen from the Presidential Range. The southeast side of the fault is downthrown, and the fault probably dips southeast (Billings, 1941, p. 914-916). The net slip is to be measured in hundreds or thousands of feet, but the precise value is unknown.

Along the thrust fault in the northwest corner of the quadrangle the Albee formation has been thrust southward over the Ammonoosuc volcanics (R. W. Chapman, 1942, p. 1538–1539).

METAMORPHISM

The metamorphism, which has been discussed by Billings (1941, p. 919–933), is syntectonic. Some rocks recrystallized without important changes in chemical composition, but to others, notably some of the schists in the Littleton formation, moving solutions added potash. The gneiss in the lower part of the Littleton formation originated through selective solution *in situ*, accompanied by the introduction of potash, soda, and lime. The gneiss formed near the end of the orogenic period, because some of the light-colored material concentrated along cleavage planes parallel to the axial planes of the folds. The gneiss shows no evidence of strain such as would be expected if the rocks had been folded subsequent to the formation of the gneiss.

LITHOLOGIC CONTROL OF TOPOGRAPHY

A colored geologic map, such as Plate 1, brings out more successfully than any other method the relation between topography and lithology. The interbedded quartzites and coarse sillimanite schists of the Littleton formation hold up most of the high peaks of the Presidential Range. Rocks of this type are resistant in other parts of New Hampshire. The gneisses of the Littleton formation are also relatively resistant; they hold up the Dartmouth Range and Mt. Bowman, as well as Mt. Clay, Mt. Monroe, and Mt. Franklin in the Presidential Range. The Ammonoosuc volcanics are relatively weak, occupying the lower slopes of the northern flank of the Presidential Range.

The rocks of the Oliverian magma series are in general the weakest in the area and underlie the lowlands. There are a few exceptions, notably Mt. Randolph (3070 feet) and Pliny Mountain (3605 feet). The Bickford granite is likewise weak, underlying the lowland south and east of the Dartmouth Range. The intrusives of the White Mountain magma series, on the other hand, are relatively resistant. The

[2] On the topographic base map upon which the geology has been overprinted, the small peak 1 mile south of the Israel River Ranger Station is erroneously called Pine Mountain. It should be called Pine Peak, in order to distinguish it from Pine Mountain in the adjacent Gorham quadrangle.

Pilot Range is held up by hastingsite-riebeckite granite. The Pliny Range is composed of hastingsite-quartz syenite and quartz monzonite. Cherry Mountain is composed of syenite, and the northwest end of the Rosebrook Range, in the southwest corner of the quadrangle, is held up by Conway granite.

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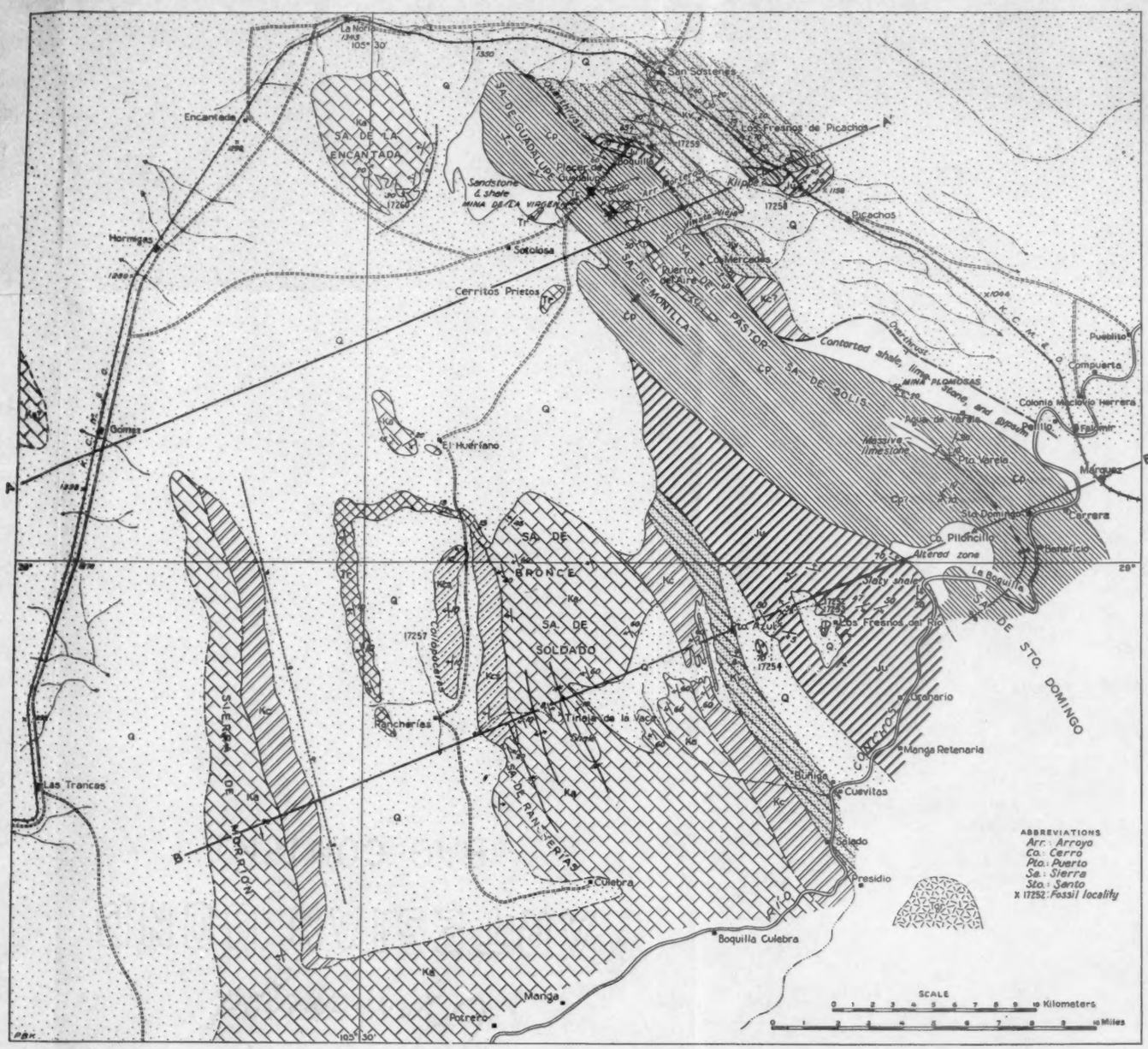
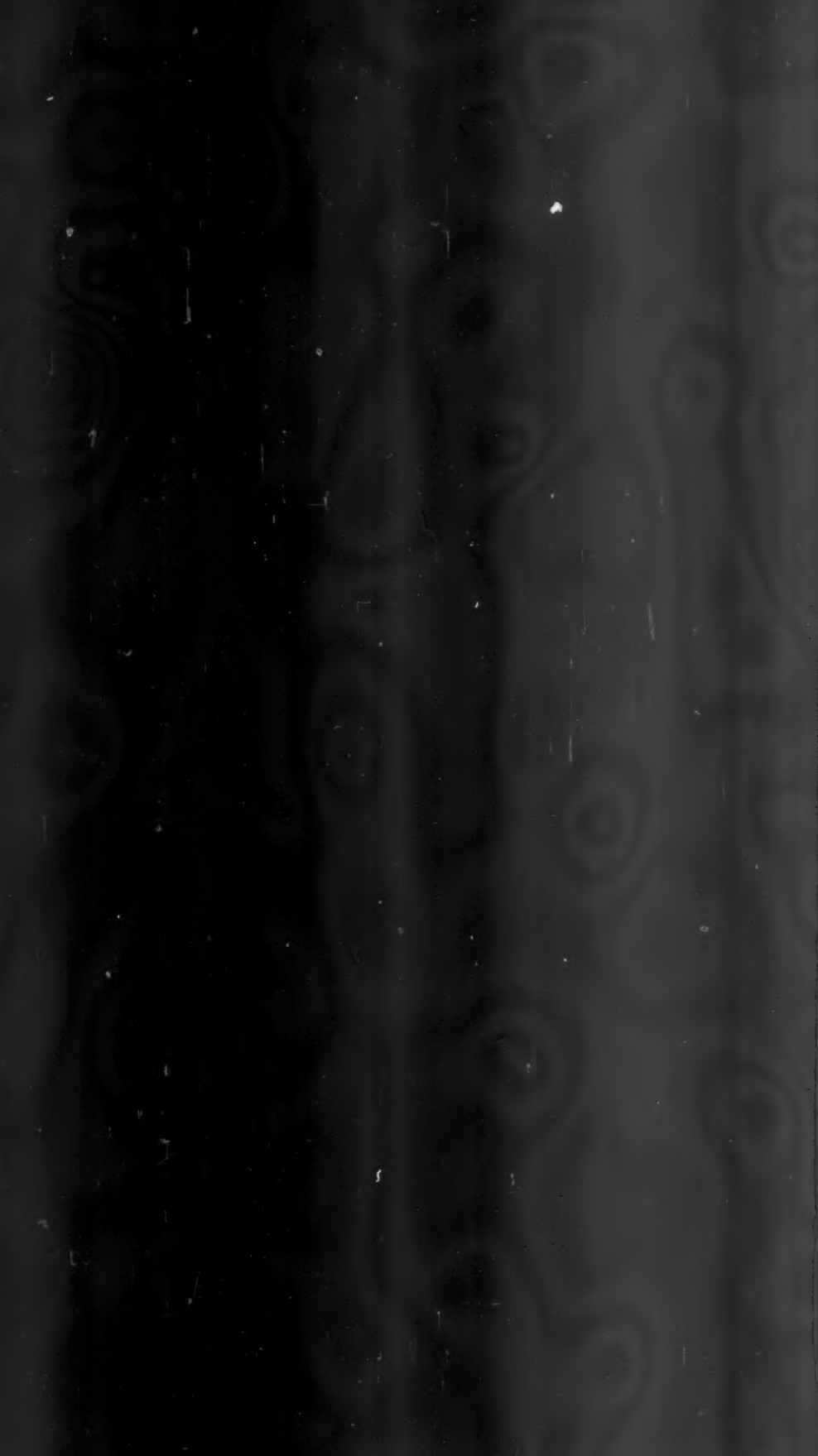


AREAL GEOLOGIC MAP AND CROSS SECTIONS, PLACER DE GUADALUPE AREA



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GEOLOGY OF A PART OF THE LOWER CONCHOS VALLEY, CHIHUAHUA, MEXICO

BY ROBERT E. KING AND W. S. ADKINS

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ABSTRACT

The lower Conchos valley of northeastern Chihuahua is crossed by mountain ranges which are a part of the Sierra Madre Oriental of Mexico. The oldest exposed formation, the Plomosas shale, sandstone, limestone, and conglomerate, somewhat metamorphosed, is believed to be Paleozoic. Above follow the Upper Jurassic La Casita shale and a thick Cretaceous section, divided into the Las Vigas red and gray clastic rocks, the Cuchillo shale, gypsum, and limestone, the Aurora limestone,

and the Chispa Summit flaggy limestone, shale, and sandstone. Early Tertiary volcanic rocks lie unconformably on the older formations, and the late Tertiary Conchos gravels fill the valleys to a depth of several hundred feet. The rocks are strongly folded along a north-northwest trend. In places the folds are overturned, and an overthrust fault with several miles horizontal throw occurs at the northeast base of the highest uplift. Normal faults parallel the trend of the folds. The main orogenic epoch was early Tertiary. After the ranges were deeply dissected, lavas covered the erosion surface, and folding recurred along pre-existing axes. Basins of interior drainage formed by the folding were filled with the Conchos gravels. As master streams connected the isolated basins, deep, narrow gorges were cut into the resistant rocks of the intervening ranges.

INTRODUCTION

In a series of mountain ranges crossing the lower valley of the Río Conchos, in northeastern Chihuahua between the cities of Chihuahua and Ojinaga, an excellent fossiliferous section of the Mesozoic is exposed. Data on this section aid in the understanding of the stratigraphy and facies changes in the Mesozoic not only of western trans-Pecos Texas, but also of the northern extension of the Sierra Madre Oriental of Mexico, of which these ranges form a part.

The stratigraphy of the lower Conchos valley was first described by Burrows (1910), who divided the section into seven formations. The oldest, the Boquilla slate, Burrows regarded as pre-Cretaceous. The succeeding Plomosas, Las Vigas, and Cuchillo were not assigned to any system, but the Aurora limestone was believed to correlate with the Edwards limestone, and the Ojinaga formation was thought to be Washita and possibly Upper Cretaceous. Burckhardt (1930, p. 83, 147–149, 187, 218) summarized all information available to him on the region and assigned Burrows' formations to approximately their correct ages.

The writers spent 2 weeks in June 1933 in a reconnaissance study of two areas: the vicinity of Cuchillo Parado and Coyame, and an area west of Falomir, in the angle formed by the Río Conchos and the Orient railroad (Fig. 1). King's participation in the trip was made possible by a grant from the Penrose Bequest of The Geological Society of America, but this study was incidental to an investigation of the Sierra Madre Occidental. The region may be reached from Chihuahua or or Ojinaga by train or by car, but the poor condition of the roads in 1933 made travel on horseback necessary in the field. In the short time available accurate measurement of sections was impossible. In the absence of satisfactory topographic base maps of the Conchos valley, pace traverses were made to fit the more accurately located points on the Chihuahua sheet of the American Geographical Society's Hispanic America maps. Plates 1 and 4 are the result of this adjustment and are only approximately correct; they are designed to show the general relationship of the geologic features described in the text.

The fossils collected by Adkins and King were studied by Dr. Ralph W. Imlay of the United States Geological Survey, who described the Jurassic fossils (Imlay, 1943a) and kindly supplied preliminary fossil lists and age determinations of the remaining faunas. The writers are indebted to Dr. Philip B. King for the drafting of Plates 1 and 4.

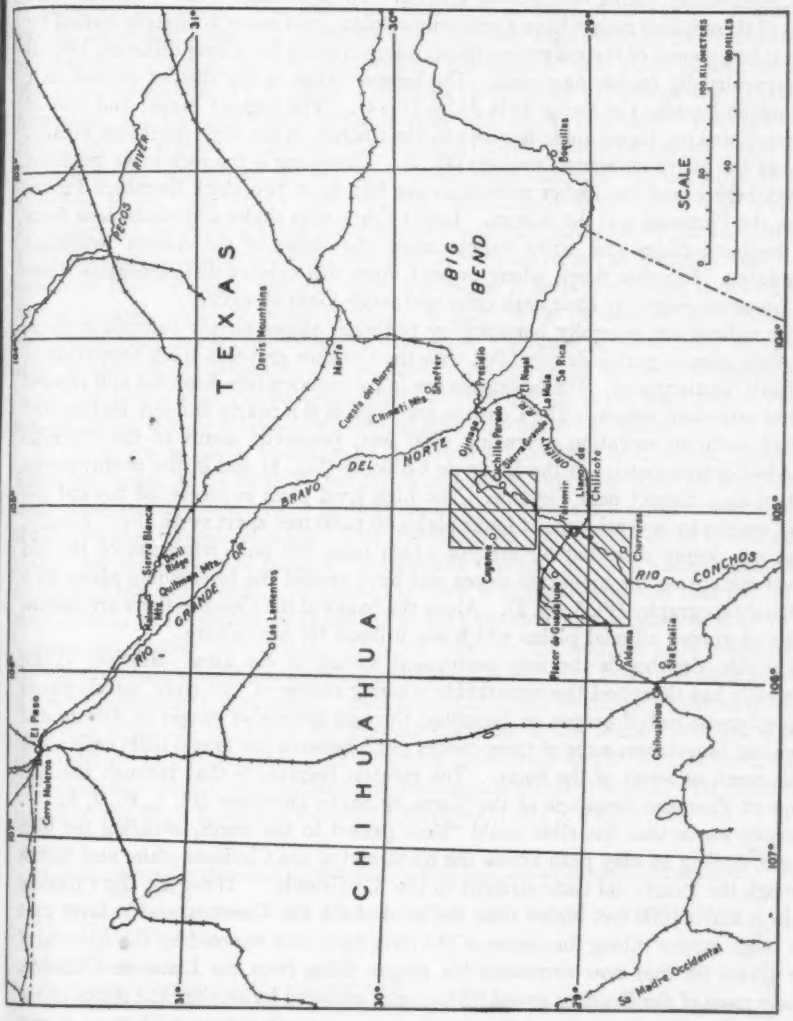

FIGURE 1.—*Regional outline map of northeastern Chihuahua*
Hatched areas are those covered by areal geologic maps, Plates 1 and 4

PHYSIOGRAPHY

The mountain ranges of the lower Conchos valley rise steeply 500 to 2500 feet from intervening plains of Conchos gravels. Their average trend is N. 30° W. Most of these folded ranges have a pronounced pitch, and many are deeply buried by gravel; hence none of the ranges continues uninterrupted for a long distance, but all are separated by coalescing plains. The longest range in the district is that east of Cuchillo Parado, the Sierra de la Aldea (Pl. 4). The highest range, and one of the most striking topographic features in the district, is the high northeast escarpment of the Sierra de Santo Domingo (Pl. 1). Limestone is the rock most resistant to weathering, and the higher mountains are formed of two thick limestone formations, the Plomosas and the Aurora. Lower Cretaceous shales and sandstones form low hogback ridges and strike valleys along the slopes of the Aurora limestone mountains. Rhyolite flows, where present, form low cuestas distinguishable from the limestone ridges by their dark color and much lower elevation.

The valleys are generally bordered by pediment slopes on the bedrock surface, and their greater part is deeply filled with the Conchos gravel, a thick formation of probable Tertiary age. The pediments are in part moderately dissected and crossed by low sandstone ridges. The Conchos gravel plain is a nearly flat and undissected surface with an elevation averaging 4000 feet, preserved south of the Cuchillo Parado-Coyame district in the Llano de Chilicote (Fig. 1) and in the northwestern part of that district near Coyame. The high level plain is succeeded toward the Río Conchos by several steps of lower plains 30 to 60 feet apart vertically. Finally, these are deeply dissected by arroyos which have left only remnants of the old gravel surface on the mountain slopes and have eroded the intervening plains to a badland topography (Pl. 3, fig. 2). Along the banks of the Conchos there are narrow strips of graded alluvial plains which are utilized for agriculture.

The Río Conchos is the only permanent stream in the area. Burrows (1910, p. 86–87) has described the remarkable winding course of this river, which passes in precipitous-walled gorges, or boquillas, through successive ranges of Aurora and Plomosas limestones; some of these ranges pitch beneath the gravel plain only a few miles north or south of the gorge. The greatest boquilla is that through the high range of Plomosas limestone of the Sierra de Santo Domingo (Pl. 1, Pl. 2, fig. 1). Burrows states that the river could "have passed to the south, avoiding the high ranges, finding an easy path across the north end of the Chilicote plain, and thence through the Puerto del Gato straight to the Río Grande." However, the Chilicote plain is about 1000 feet higher than the level of the Río Conchos, and in large part the "high ranges" along the course of the river have been exposed by the removal of the gravel fill that now surrounds the ranges rising from the Llano de Chilicote. Where most of the Conchos gravel fill has been removed by erosion, the slopes of the ranges below the remnants of the gravel plain are much steeper and more rugged than the upper slopes. Above the narrow inner gorges of the Conchos boquillas which lie below the remnants of the old surface, the valley slopes are less steep, but still form profound cuts across the mountains.

STRATIGRAPHY

PALEOZOIC (?)

Plomosas formation.—The Plomosas formation consists of somewhat metamorphosed shale, sandstone, and limestone which form the high Sierra de Santo Domingo southwest of Falomir, and the northwestern extension of that range to and beyond Placer de Guadalupe (Pl. 2, fig. 2). Burrows (1910, p. 89–92) named the Plomosas formation for the excellent exposures near the Mina Plomosas. Burrows distinguished as another formation the Boquilla slates, which he placed below the Plomosas, and which had as their type locality the exposure "in the gorge of the Conchos River, just above the Boquilla, near Santo Domingo." The writers examined the formations along the Conchos for several miles above the head of the Boquilla, east of Los Fresnos del Río, but did not traverse the Boquilla itself. It appeared that the type Boquilla slate was either a metamorphosed facies of the Upper Jurassic shale or, more probably, a slaty shale member of the Plomosas formation which occurs immediately to the east. Because of uncertainty as to the type locality of the Boquilla, and because of the existence of the well-established name "Boquillas flags" for an Upper Cretaceous formation in the Big Bend of Texas not far to the east, it is considered best to reject the name "Boquilla."

In the Sierra de Santo Domingo on the north side of the Conchos, the Plomosas formation crops out in an anticlinal belt 5 miles wide, probably with an overthrust fault along its northeast base. In the core of the anticline is a massive white limestone with rare crinoid columns. This is overlain by about 1000 feet of brown slaty shale. On the southwest flank of the anticline this unit is much altered, probably by contact metamorphism. In places the shale is so highly silicified that it rises in steep pillars, and elsewhere it is altered so that the rock appears superficially to be igneous, but retains its bedding. This unit may be the Boquilla slate of Burrows. On the northeast side of the anticline, northeast of Puerto Varela, the slate is overlain by conglomeratic limestone. This limestone seems to merge to the northwest along the mountain front into the typical Plomosas of the Mina Plomosas, where the limestone of the mountain front, dipping an average of 20° NE., is hard, dark gray, and thin-bedded, and contains rare and obscure traces of fossils. The following section at the Mina Plomosas is given by Burrows (1910, p. 89–92):

Top	Feet
6. Shale containing three interbedded layers of limestone, the latter with small deposits of lead and zinc	160
5. Massive limestone containing large ore bodies; forms mountain front at Mina Plomosas	450
4. Shale	180
3. Conglomerate	80
2. Limestone containing iron and copper ore	200
1. Quartzite, much shattered in places, showing a network of quartz veinlets and an occasional trace of copper	100

Southeast from Placer de Guadalupe to the Puerto del Aire are two high Plomosas limestone ridges, the Sierras de Monilla and del Pastor, separated by a valley in which there is a chain of rhyolite intrusions. The whole sedimentary succession dips 50–70° NE. The northeastern limestone, stratigraphically higher, is overlain

TABLE 1.—*Formations exposed in Placer de Guadalupe area and Cuchillo Parado area, Northeastern Chihuahua*

	Stage	Zone Fossils	Formation	Description
TERTIARY		deer (?) bones	Late Tertiary, including Conchos gravel (Qa)	Coarse, well-sorted gravel, and interbedded clay, 500+ ft.
			Volcanic rocks (Tv)	Rhyolite flows
CRETACEOUS	Maestrichtian to Coniacian	Sphenodiscus Placenticeras Texanites	Late Upper Cretaceous	(not seen in area studied)
	Turonian	Prionotropis Coilopoceras Romaniceras	Chispa Summit (Kcs) formation	Upper part: shale and some sandstone, *Coilopoceras*, *Romaniceras*. Lower part: flaggy limestone, *Inoceramus*. About 3200 ft.
	Cenomanian-Albian	Enallaster Exogyra texana Oxytropidoceras Orbitolina texana	Aurora (Ka) limestone	Top: thin and massive limestones, Washita fossils. Middle: marly limestone, Kiamichi fossils. Bottom: thick Fredericksburg-Trinity limestones. About 5000 ft.
	Lower Albian-Aptian	Douvilleiceras Trigonia taffi Exogyra quitmanensis Dufrenoya	Cuchillo formation (Kc)	Shale, gypsum. 600–2000 ft.
	Neocomian (part)		Las Vigas formation (Kv)	Shales and sandstones. 4000+ ft.
JURASSIC	Portlandian	Kossmatia Virgatosphinctes Subplanites	La Casita formation (Ju)	Black shales with thin limestones and sandstones. 2000+ feet.
	Kimmeridgian	Waagenia		
PALEOZOIC (?)		Crinoids	Plomosas formation (Cp)	Sandstone, shale, limestone and conglomerates. 8000+ feet.

with apparent conformity by about 1700 feet of coarse sandstone which contains several layers of very coarse conglomerate.

At Placer de Guadalupe (Pl. 2, fig. 2) the succession is interrupted by rhyolite intrusions. The lowest member, apparently, is shale and calcareous sandstone at the Mina de la Virgen, and is overlain just northeast of that mine by limestone about 700 feet thick, which forms a low hogback dipping 20° NE. The limestone contains abundant crinoid columns up to nearly 1 cm. in diameter, and this is evidently the same locality reported by Böse (1923, p. 134–135) near Placer de Guadalupe, where *Nerinea* and *Millericrinus* are said to occur in a limestone. Above the limestone follows about 2100 feet of shattered quartzite, interbedded with sandy shale, and

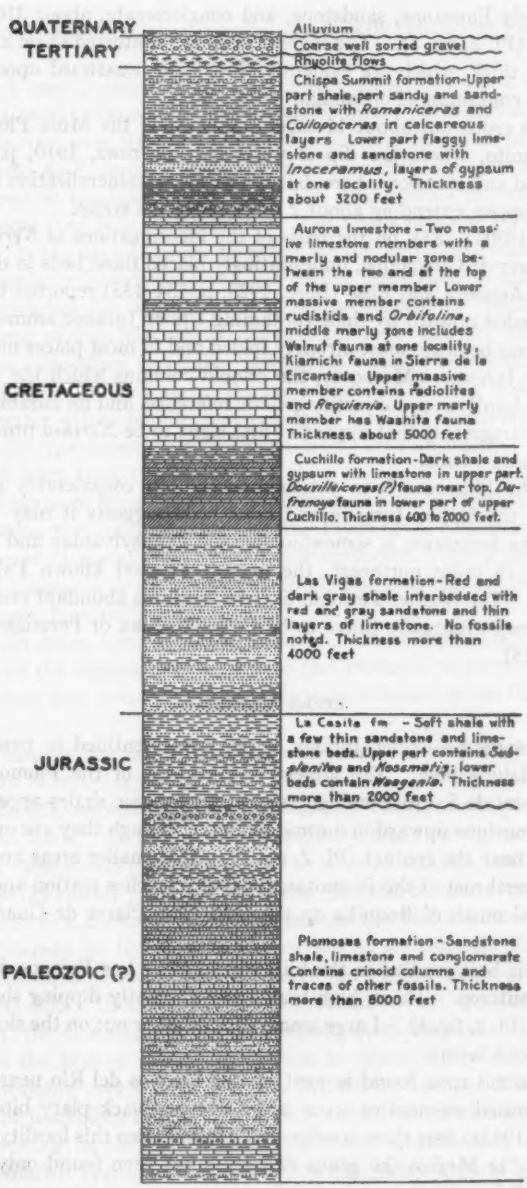
QUATERNARY
TERTIARY
CRETACEOUS
JURASSIC
PALEOZOIC (?)
Alluvium
Coarse well sorted gravel
Rhyolite flows
Chispa Summit formation–Upper part shale, part sandy and sandstone with Pomeniceras and Collopoceras in calcareous layers Lower part flaggy limestone and sandstone with Inoceramus, layers of gypsum at one locality. Thickness about 3200 feet
Aurora limestone – Two massive limestone members with a marly and nodular zone between the two and at the top of the upper member Lower massive member contains rudistids and Orbitoline, middle marly zone includes Walnut fauna at one locality, Klamichi fauna in Sierra de la Encantada Upper massive member contains radiolites and Requienia. Upper marly member has Washita fauna Thickness about 5000 feet
Cuchillo formation–Dark shale and gypsum with limestone in upper part. Douvilleiceras(?) fauna near top. Durfrenoya fauna in lower part of upper Cuchillo. Thickness 600 to 2000 feet.
Las Vigas formation–Red and dark gray shale interbedded with red and gray sandstone and thin layers of limestone. No fossils noted. Thickness more than 4000 feet
La Casita fm – Soft shale with a few thin sandstone and limestone beds. Upper part contains Cardioniites and Neocomites; lower beds contain Haeneniia. Thickness more than 2000 feet
Plomosas formation–Sandstone shale, limestone and conglomerate Contains crinoid columns and traces of other fossils. Thickness more than 8000 feet

FIGURE 2.—*Generalized stratigraphic column showing units known in the area mapped*

at Boquilla, sandy limestone, sandstone, and conglomerate, about 3100 feet thick, forming a ridge (Pl. 2, fig. 3). The highest beds are contorted shale and sandstone about 2000 feet thick, which are evidently thrust northeastward upon softer shale and sandstone containing Portlandian ammonites.

The Plomosas crops out about 11 miles southeast of the Mina Plomosas in the Cerro de Coyamito, where the dip is westward (Burrows, 1910, p. 91). Small quantities of lead and zinc occur here, but the principal mineralization is iron gossan with traces of copper, extending about 2 miles along the strike.

Burckhardt (1930, p. 83), on the basis of the identifications of *Nerinea* and *Millericrinus* at Placer de Guadalupe, unhesitatingly placed those beds in the Oxfordian, especially since Aguilera and Böse (Böse, 1923, p. 134–135) reported that the limestone was succeeded upward by shale containing Upper Jurassic ammonites. However, the Plomosas beds are more strongly folded and in most places more indurated than the Upper Jurassic. Moreover, the crinoid columns which the writers found in the limestone hardly seem to justify generic reference, and no indubitable *Nerinea* were seen; some fragments that appear at first sight to be *Nerinea* prove to be cross sections of crinoid stems.

The age of the Plomosas is as yet unknown. The considerably greater metamorphism than the Upper Jurassic and later beds suggests it may be Paleozoic. Lithologically the formation is somewhat like the Pennsylvanian and Permian near Shafter, Texas, 75 miles northeast, the nearest exposed known Paleozoic strata (Skinner, 1940). The Shafter Permian likewise contains abundant crinoid columns. The Plomosas may eventually prove to be Pennsylvanian or Permian (R. E. King, 1942, p. 114–115).

UPPER JURASSIC

La Casita formation.—Upper Jurassic rocks were identified in two parts of the Placer de Guadalupe area. The largest is southwest of the Plomosas limestone range of the Sierra de Santo Domingo, where the Jurassic shales appear to succeed the Plomosas limestone upward in normal sequence, though they are overturned and altered to slate near the contact (Pl. 2, fig. 1). The smaller areas are northeast of the supposed overthrust of the Plomosas, between Picachos station and Los Fresnos de Picachos, and north of Boquilla on the road from Placer de Guadalupe to San Sóstenes (Pl. 1).

The Jurassic is best studied in the hills surrounding Los Fresnos del Río, in the largest area of outcrop. There, high bare mesas of gently dipping shale rise above the valley floor (Pl. 2, fig. 4). Large ammonites weather out on the slopes of various highly fossiliferous layers.

The lowest faunal zone found is west of Los Fresnos del Río near Puerto Azul, where many crushed ammonites occur in a brownish-black platy bituminous limestone. Imlay (1943a) lists three species of *Waagenia* from this locality (No. 17254),[1] and states that "in Mexico the genus *Waagenia* has been found only in the upper

[1] These numbers refer to localities shown on Plate 1 and Plate 4. For description of Jurassic localities, *see* Imlay (1943a, p. 527–530).

part of the middle Kimmeridgian directly above beds containing *Glochiceras fialar* (Oppel)."

Most of the Upper Jurassic in this area is soft shale with a few thin sandstone layers, having a total thickness of more than 2000 feet. The exact sequence of beds is uncertain, as the base was not observed. Collections made from two faunal zones near Puerto Azul consist exclusively of ammonites. Imlay (1943a) has listed from these zones at localities 17252 and 17253 two species of *Subplanites*, three of *Virgatosphinctes*, and four of *Kossmatia*. The fossils indicate a Portlandian age.

The Jurassic in the area between Picachos station and Los Fresnos de Picachos consists of irregularly folded shale and sandstone, apparently forming part of the overridden beds below the overthrust of Plomosas limestone. Beside the railroad 2 miles northwest of Picachos station, ammonites were collected (Locality 17258) which have been described by Imlay (1943a) as *Involuticeras picachosense* Imlay and *Subplanites fresnosensis* Imlay. As the former indicates a middle Kimmeridgian and the latter a late middle Kimmeridgian to lower Portlandian age, Imlay suggests that the specimens were collected from different beds. However, the two ammonites came from the same spot.

The Jurassic north of Boquilla is soft sandstone and shale, dipping steeply northeastward, between the contorted beds of the main mass of the Plomosas and a detached outlier of Plomosas limestone 0.3 mile northeast. Imlay (1943a) identified two species of *Kossmatia* from locality 17259, 1 mile northeast of Boquilla. Both indicate an upper Portlandian age.

Jurassic fossils have been reported from Cuchillo Parado (Burckhardt, 1910; 1930, p. 83), but the writers were unable to find evidence of pre-Cretaceous strata there and conclude that these fossils probably were collected in the Placer de Guadalupe area.

The Upper Jurassic section of the Conchos valley, as shown by Imlay, ranges in age from middle Kimmeridgian to upper Portlandian. To the north, it correlates in part with the Malone formation of westernmost Texas, the only exposed marine Jurassic in that State. It is similar lithologically and faunally to the La Casita formation, the type locality of which is in southern Coahuila, and Imlay (1943b, Table VI, p. 1473) placed the Conchos valley Jurassic in that formation. In the Conchos valley section the lower Kimmeridgian and the Tithonian are unrepresented, but these stages may be found after further study; for example Tithonian in the considerable thickness of shales present above the highest ammonites collected at Los Fresnos del Río. Unless the Plomosas formation is Oxfordian, as suggested by Burckhardt, the Oxfordian is likewise missing from the Conchos valley section as well as from the Malone Mountains section in Texas, where the lower Kimmeridgian unconformably overlies the Permian (Albritton, 1938, p. 1758–1764). This fact suggests the possibility that the Oxfordian sea did not extend as far north in the Mexican geosyncline as did the Kimmeridgian and Portlandian. Moreover, the absence of Tithonian faunas in both the Conchos valley section and the Malone section might suggest a regression of the sea from the northern end of the geosyncline at the end of Portlandian time. However, *Steueroceras*, identified by Burckhardt (1930, p. 83) was recorded from a locality 53 miles E.SE. of Cuchillo Parado, near Sierra Rica.

CRETACEOUS

Las Vigas formation.—The Las Vigas formation consists of red and dark-gray shale, regularly interbedded with red and gray slabby sandstone and thin layers of limestone. The formation is probably 4000 or more feet thick. At the type locality, the Mina las Vigas (Pl. 4), the formation contains nodules and veins of copper ore. The Las Vigas crops out along the foot of the high ranges of overlying limestone and is characterized by an alternation of sharp ridges of sandstone with narrow shale valleys (Pl. 3, fig. 1). The first geological description of this area was by Weed (1902, p. 402–404, 412–414).

No fossil invertebrates were found by the writers in the formation. However, the Las Vigas grades upward into the fossiliferous Cuchillo formation, and from its position above the Upper Jurassic the Las Vigas appears to be Lower Cretaceous.

The name Las Vigas has been applied to a clastic formation of Lower Cretaceous age in western trans-Pecos Texas, in southern Coahuila, and eastern Durango (Imlay, 1944). Assuming that all the beds which have been called Las Vigas are truly correlative with the formation in its type area, the type Las Vigas then must be of Neocomian age. Perhaps further study of the Conchos valley section will reveal the presence of marine lower Neocomian beds equivalent to the Taraises formation which is widespread farther south in the Mexican Cretaceous geosyncline.

Cuchillo formation.—The Cuchillo formation is chiefly dark shale and gypsum, with scattered thin layers of limestone and sandstone, and thicker beds of nodular limestone. The type locality (Burrows, 1910, p. 95–96), is on the road from Cuchillo Parado to the Mina Aurora (Pl. 4), where the lower three-fourths of the formation is mostly gypsum with scattered thin limestone layers, and the upper fourth is alternating gypsum, shale, and fossiliferous limestone, with the limestone layers becoming thicker toward the top. The name of the village of Cuchillo Parado, meaning "erect blade," refers to a small sharp ridge of vertical Las Vigas strata on the west side of the Conchos, 1 mile north of the village, and is not related to any feature of the type locality of the formation. On the bank of the Río Conchos, salt springs issue from the outcrop of the lower Cuchillo, indicating either the flushing of rock salt from the formation by meteoric water or the outlet of connate salt water. On Cerro Chino, northwest of Cuchillo Parado, the formation is gypsiferous shale with layers of sandstone. Burrows (1910, p. 95) states that at Chorreras, south of the Conchos (Fig. 1), the formation is almost entirely clay, without gypsum. The thickness of the Cuchillo ranges from 600 to 2000 feet.

Section of Cuchillo formation, exposed from Abuja Colorada to gap on west side of Cerro Chino, on trail to La Bonita

	Feet
Limestone and sandy limestone capping mountain	
Black shale, with strata of limestone and sandstone; age probably Lower Albian; about	600
Marl and marly limestone; level of gap, Loc. 17251K; *Douvilleiceras?, Parahoplites;* Lower Albian (?) age; about	20
Blackish shales with scattered thin nodular limestone seams; echinoids, rare *Exogyra quitmanensis* Cragin; Loc. 17269; about	200
Prominent sandstones, nodular limestones and marl; *Exogyra quitmanensis* Cragin (abundant), *Trigonia taffi* Cragin (common); about	50

FIGURE 1. CANYON OF CONCHOS RIVER
East of Los Fresnos del Río. Jurassic shale on right; contact metamorphosed Plomosas (?) formation on left.

FIGURE 2. PLACER DE GUADALUPE
View northwest toward Sierra de Guadalupe, formed of Plomosas limestone.

FIGURE 3. PLOMOSAS LIMESTONE
Minor folds adjacent to fault contact with Jurassic shale, north of Boquilla beside Placer de Guadalupe-San Sóstenes road.

FIGURE 4. HILLS OF LA CASITA SHALE
View north from between Puerto Azul and Los Fresnos del Río.

FIGURE 1. LAS VIGAS SANDY LIMESTONE
South of Mina Las Vigas.

FIGURE 2. CONCHOS GRAVEL
Bluff east of Cuesta del Sobaco, 3 miles south of Cuchillo Parado.

CRETACEOUS AND TERTIARY OUTCROPS

	Feet
Black gypsiferous shale, some sandstone strata in basal part; *Dufrenoya justinae* (Hill) (common), *Hypacanthoplites* sp., *Exogyra quitmanensis* Cragin (common), *Lucina* sp. (abundant), *Ostrea* sp., *Lopha* sp., *Astarte* sp., *Trigonia* aff. *taffi* Cragin; *Meyeria mexicana* Rathbun, and other fossils; Loc. 17251; about	400

The only identifiable fossils found in the Cuchillo were in the upper half of the formation, where two abundantly fossiliferous zones occur. The largest collection from the lower zone was made on Cerro Chino (locality 17251; marked "Sandst. bed with *Trigonia taffi*" on Pl. 4). The following fossils are listed from this locality by Imlay:

Dufrenoya justinae (Hill) (= *D. texana* Burckhardt)
Dufrenoya sp. ind.
Hypacanthoplites sp.
Cheloniceras? sp.
Exogyra quitmanensis Cragin
Exogyra sp. aff. *E. texana* Roemer
Ostrea (Lopha) sp.
Ostrea sp.
Astarte sp.
Trigonia aff. *T. taffi* Cragin
Trigonia sp.
Lucina spp.
Arctica sp.
Corbula sp.
Tapes sp.
Gervilliopsis sp.
Pterocerella? sp.

Also collected from this locality was the decapod crustacean *Meyeria mexicana* Rathbun (Rathbun, 1935, p. 17–18, Pl. 26). Imlay notes that

"this fauna is placed in the upper Aptian on the basis of the occurrence of *Dufrenoya justinae*. Most of the pelecypod species are undescribed, but occur in the lower Trinity of the Quitman Mountains of Texas, the Little Hatchet mountains of New Mexico, and at several places in southeastern Arizona."

The following is a list by Imlay of fossils from the lower Cuchillo fossil zone at the type locality of the formation, 2½ miles northeast of Cuchillo Parado on the road from the Mina Aurora to the Río Conchos (locality 17261 marked *Dufrenoya* on Pl. 4):

Dufrenoya sp.
Hypacanthoplites sp.
Lucina sp.
Trigonia spp.
Tapes sp.
Arctica sp.
Exogyra sp.
Echinoids undetermined

The zone is also well represented east of the Mina las Vigas (Pl. 4), but no collections were made there.

The upper fossil zone in the Cuchillo is less fossiliferous. The only collection from it made by the writers was at locality 17251K, on Cerro Chino, west of and from beds overlying the sandstone with *Trigonia* aff. *T. taffi* (localities 17251 and 17269). Imlay lists these fossils from the collection: *Douvilleiceras?* sp., *Cheloniceras?* sp., and *Parahoplites?* sp. Imlay states that "these fossils probably represent Lower Albian, but are too fragmentary for definite identification." Above Loc. 17251K is about 600 feet of Upper Cuchillo marls, of Lower Albian age.

The paleontologic evidence therefore shows that the upper third of the Cuchillo in its type area is mostly of lower Albian age. The middle third, containing *Dufrenoya*, is of Aptian age. The lower Cuchillo is still poorly zoned but is probably mostly lower Aptian.

The Cuchillo has been identified in the southern Quitman Mountains (Fig. 1) where it is said to be represented by more than 3000 feet of shale, marl, limestone, and sandstone (Scott, 1940, Pl. 55, facing p. 978). A formation of dolomitic limestone and gypsum occurring in southern Coahuila has been referred to the Cuchillo (Imlay, 1944). The zones of *Dufrenoya* and *Douvilleiceras* occur in the upper part. The Cuchillo directly overlies the Paleozoic in the southern part of the Coahuila Peninsula, the foreland of the Mexican geosyncline. The formation is a marginal facies of the upper Aptian and lower Albian which grades southward into limestone in the geosyncline.

The Cuchillo and its equivalents are the first formations which were deposited beyond the margins of the Mesozoic geosynclines of Mexico, western Texas, and the east Texas basin, and they overlap upon the Paleozoic rocks of the forelands.

Aurora limestone.—The main mountain-forming limestone of the Conchos valley is the Aurora, named from the Mina Aurora, in the Sierra de la Aldea northeast of Cuchillo Parado (Pl. 4) (Burrows, 1910, p. 96–98). The Aurora consists of two thick massive limestone members with a marly and nodular zone between the two massive members and another at the top of the upper member. The thickness of the formation is about 5000 feet. According to Burrows, the Aurora limestone contains the principal mineral deposits of the region, including the important Mina Santa Eulalia near the city of Chihuahua. In the area studied by the writers, lead ore of the Mina Aurora is the principal ore body known in the Aurora limestone.

The lower massive member of the formation contains rudistids and *Orbitolina* and is at least partly of Glen Rose age. Northeast of the Mina las Vigas (Pl. 4, "Walnut zone") the marly zone overlying it contains *Exogyra texana* and *Heteraster* and is probably of Walnut age.

Reddish marly limestone below the upper massive member of the Aurora at the southeast foot of the Sierra de la Encantada (Pl. 1) contains the following fossils, identified by Imlay (locality 17260):

Engonoceras cf. *E. stolleyi* Böhm
Oxytropidoceras (*Adkinsites*) cf. *O. belknapi* (Marcou)
Oxytropidoceras (*Adkinsites*) cf. *O. chihuahuensis* Böse
Oxytropidoceras sp.
Tylostoma chihuahuense Böse
Tylostoma sp.
Aporrhais? cf. *A. subfusiformis* (Shumard)
Aporrhais? sp.
Helicocryptus sp.
Turbo? chihuahuensis Böse
Tapes aldamensis Böse
Homomya spp.
Plicatula incongrua Conrad
Pecten (*Neithea*) *occidentalis* (Conrad)
Trigonia guadalupae Böse
Nucula guadalupae Böse
Ostrea sp.
Cardium subcongestum Böse
Cardita posodae Böse

Pinna guadalupae Böse
Sphaera roblesi Böse
Protocardia multistriata (Shumard)
Exogyra texana Roemer
Inoceramus sp.
Trapezium? sp.
Salenia mexicana Schlüter
Enallaster sp.
Corals indetermined

This locality and its fauna were first studied by Böse (1910). Imlay states that the fauna

"may be assigned to upper Fredericksburg on the basis of the presence of *Oxytropidoceras*. Böse found *Gryphaea navia* Hall at La Encantada, and its presence would indicate a Kiamichi age. However, that species was not found in the collection in hand."

The upper massive limestone of the Aurora contains radiolites and *Requienia* and is of Fredericksburg and Washita age.

The upper thin-bedded member of the Aurora is well exposed east of El Fortín (Pl. 4) and east of Rancherías (Pl. 1). At Cuesta del Álamo, 1.8 miles east of El Fortín, the following fossils, as identified by Imlay, were collected (locality 17262):

Pecten (*Neithea*) sp.
Ostrea (*Lopha*) *carinata* Lamarck
Enallaster cf. *E. bravoensis* Böse
Enallaster cf. *E. texanus* Roemer
Sauvagesia? sp.

Imlay remarks that

"this lot of fossils is probably of Washita age as suggested by the presence of an echinoid like *Enallaster bravoensis*. Also *Ostrea carinata* is rather uncommon below the Washita."

The Del Rio and Buda appear to be absent in this area, as they are locally in parts of Trans-Pecos Texas.

Vivar (1925) in his study of the Ojinaga region introduced the name "Sierra Grande group," which he divided into the El Álamo, Santa Cruz, and Mangas formations. The El Álamo formation is dark impure limestone with *Orbitolina texana*, and the Santa Cruz a hard gray cherty limestone. An unnamed member of gray shale with sandy nodules is correlated with the Del Rio, and the compact, nodular Mangas limestone at the top of the Sierra Grande group is regarded as Buda. The El Álamo and Santa Cruz limestones are evidently equivalent to the Aurora limestone. In the Big Bend of Texas, the Glen Rose, the Fredericksburg, and the Georgetown form, as does the Aurora, a combined limestone mass which is commonly referred to as the Devils River limestone, though the Devils River as originally defined does not include the Glen Rose (Adkins, 1933, p. 325). In the Quitman Mountains (Fig. 1) the Glen Rose equivalent alone, consisting of marl and limestone with sandstone layers in the upper part, is 4500 feet thick (Scott, 1940, pl. 55, facing p. 978). This appears to be a more marginal facies than the typical Aurora.

The name "Aurora limestone" has been applied to a reef facies of lower and middle Albian age marginal to the Mesozoic geosyncline on the site of the Coahuila Peninsula in southern Coahuila and eastern Durango. Imlay (1944, p. 1185) separates the limestone of Glen Rose age from the Aurora limestone in the Conchos valley.

The Mina Aurora is in the beds of Glen Rose age; hence restriction of the name "Aurora" to beds above those at the type locality does not seem justifiable. Future detailed mapping will no doubt result in the subdivision of the Aurora.

Chispa Summit formation.—Shale interbedded with thin sandstone layers and flaggy limestone overlies the Aurora. The unit corresponds to the Chispa Summit formation, the type locality of which is in the western Big Bend of Texas (Adkins, 1933, p. 426, 431). The lower part of the Ojinaga formation of Burrows (1910, p. 100–101) included the upper thin-bedded member of the Aurora and the beds here referred to the Chispa Summit formation. The Ojinaga formation of Vivar (1925) is probably identical with the Chispa Summit of the present paper, but is of a somewhat different facies, which is apparently transitional from the shale of the Cuchillo Parado area to the Boquillas flags facies of the southern Big Bend of Texas. Imlay (1944, p. 1184) refers to the formation here called Chispa Summit as "Ojinaga."

In the areas studied by the writers, the Chispa Summit formation occurs in three synclines, those of El Álamo and Sobaco in the Cuchillo Parado area (Pl. 4) and Rancherías in the Placer de Guadalupe area (Pl. 1). The lower part of the formation in both areas is flaggy limestone and sandstone containing *Inoceramus*, with a layer of gypsum noted in the Sobaco syncline. Above, in the Cuchillo Parado area is clay shale, but at the Rancherías locality the upper Chispa Summit is sandy shale and sandstone. The formation is probably 3200 feet thick. With the exception of the *Inoceramus* beds in the lower flaggy member, the principal fossil zones are in calcareous shales in the upper part of the formation.

From west of El Álamo (locality 17255; Pl. 4, marked "*Romaniceras*") the following forms were identified by Imlay:

Romaniceras cf. *R. cumminsi* Adkins
Romaniceras sp. A
Romaniceras loboense Adkins
Romaniceras sp. B
Romaniceras sp. C
Romaniceras cf. *R. mexicanum* Jones
Pseudotissotia? cf. *P. coahuilensis* Jones
Pseudotissotia? n. sp.
Prionotropis sp. A

From locality 17256, west of Sobaco (Pl. 4, marked "*Romaniceras*") Imlay has identified the following:

Pseudotissotia? cf. *P. coahuilensis* Jones
Coilopoceras sp.
Romaniceras cf. *R. cumminsi* Adkins
Romaniceras loboense Adkins
Prohauericeras sp.
Prionotropis sp. A
Prionotropis sp. B (similar to *P. woolgari*)
Prionotropis sp. C
Aporrhais spp.
Amauropsis? sp.
Avicula? cf. *A. aguilerae* Böse

Imlay writes:

"Collections 17255 and 17256 contain many species in common and probably represent about the same stratigraphic level as unit 3 of the section near Chispa Summit, Texas, as described by W. S. Adkins (1931, p. 37). Adkins referred this unit questionably to early upper Turonian, apparently on the basis of the abundance of *Romaniceras* contained in it and the presence of lower Turonian ammonites in the underlying units."

The ammonite called "*Pseudotissotia*?" is probably a new genus belonging to the family Vascoceratidae.

The following fossils are listed by Imlay from the Rancherías locality (no. 17257; Pl. 1, marked "*Coilopoceras*"):

Coilopoceras spp. (several species)
Romaniceras cf. *R. cumminsi* Adkins
Romaniceras cf. *R. toribioense* Jones
Romaniceras sp. A
Romaniceras sp. C
Prionotropis sp. D (similar to *P. hyatti* Stanton)
Prionotropis sp. E
Prionotropis sp. F
Inoceramus cf. *I. labiatus* Schlotheim

Imlay states that this collection represents a different stratigraphic level than the Sobaco and El Álamo collections (17255 and 17256)

"as shown by the abundance of *Coilopoceras* and the presence of different species of *Prionotropis*. Adkins (1933, p. 432–437) has shown that in Texas the zone of greatest abundance of *Coilopoceras* occurs stratigraphically higher than the zone of greatest abundance of *Romaniceras*. J. B. Reeside, Jr. says the same relationship occurs in New Mexico. One of the species of *Prionotropis* is very similar to *P. hyatti* Stanton which occurs in the Carlile formation of upper Turonian age. In any case the abundance of *Coilopoceras*, *Romaniceras*, and *Prionotropis* is fairly good evidence of an upper Turonian age."

The Chispa Summit formation is equivalent to the Eagle Ford formation of upper Cenomanian and Turonian age. From east to west in the Conchos valley region a progressive change in facies occurs. In the southern Big Bend of Texas the Chispa Summit equivalent is the Boquillas flaggy limestone with *Inoceramus*. South of Ojinaga is calcareous shale with interbedded flaggy limestone, the typical Ojinaga formation. In the Cuchillo Parado area is flaggy limestone overlain by clay shale. Southwest of Placer de Guadalupe is flaggy limestone overlain by sandy shale and sandstone.

The ammonite fauna of the Chispa Summit formation is closely similar to that of the Indidura formation of southern Coahuila. The Indidura is a thin, flaggy facies overlying the site of the Coahuila Peninsula, which thickens and becomes more clastic southward in the geosyncline (Imlay, 1944).

Late Upper Cretaceous.—The writers did not find younger Cretaceous formations than the Chispa Summit in the areas studied, but Coniacian (Austin chalk) to Maestrichtian (Navarro) equivalents have been described by various writers from the Ojinaga basin, east of the Cuchillo Parado area (Burrows, 1910, p. 101; Imlay, 1944, p. 1184; Vivar, 1925).

TERTIARY

Volcanic rocks.—The lower Conchos valley lies between two regions of important volcanic activity in the early Tertiary. To the northeast is the volcanic belt of the Chinati and Davis Mountains and the Cuesta del Burro. Western trans-Pecos Texas and most of the region westward from the vicinity of the city of Chihuahua is covered by volcanic rocks. In the Placer de Guadalupe and Cuchillo Parado areas are small remnants of thin but formerly extensive rhyolite flows. The largest

lava outcrop is on the flanks of the Rancherías syncline southwest of Placer de Guadalupe (Pl. 1). Other remnants occur near Coyame and on the flanks of the Sobaco syncline (Pl. 4). The lava weathers to a reddish color. It dips at uniformly lower angles than the underlying Cretaceous strata and therefore must have been poured out during a time of quiescence between two orogenic epochs.

Burrows (1910, p. 102) reports andesite agglomerate forming low hills around Placer de Guadalupe. His map shows a belt of eruptive rock extending from San Sóstenes to Picachos. The writers found only igneous intrusions and sedimentary rocks in those areas.

Conchos gravels.—Several hundred feet of coarse gravel interbedded with clay (Pl. 3, fig. 2) was named the Conchos gravels by Burrows (1910, p. 102). The boulders in the gravel rarely exceed a foot in diameter and are generally well sorted. The gravels are coarser near the mountains, toward which they rise as fans. In places the gravel is cemented by calcium carbonate to form a hard caliche. Vertebrate bones are locally reported to occur in the gravels; we collected one such bone, a mandible of a (?) deer.

No evidence of the age of the gravels has been observed in the Conchos valley except that the gravels appear to be cut by normal faults. Recent faulting has been observed in parts of western Texas; therefore, the faulting of the gravels does not necessarily indicate they were deposited in the Tertiary, when the greatest amount of faulting occurred. Albritton (1938, p. 1768–1769) has presented evidence suggesting a Pliocene age for basin deposits near the Malone Mountains which may be contemporaneous with the Conchos gravels. The age of the Conchos gravels may be either Tertiary or Quaternary; on the map legends (Plates 1 and 4) they are included in the Quaternary.

INTRUSIVE ROCKS

The only intrusive rocks in the areas studied occur in the Plomosas formation. A strike valley between two ridges of Plomosas limestone near and southeast of Placer de Guadalupe contains a number of small irregular bodies of intrusive rhyolite. The rhyolite probably was the source of the mineralizing solutions which formed near-by veins of silver- and lead-bearing calcite. To the southeast on the same line of strike, on the north side of the Río Conchos, the shale of the Plomosas formation has been metamorphosed, possibly as a result of proximity to a buried igneous mass. Burrows (1910, p. 102) reports the occurrence in the Boquilla of the Río Conchos through the Sierra de Santo Domingo of an andesitic dike more than 400 feet thick, continuing northward nearly 5 miles. This was not seen by the writers, and its location is not known with sufficient accuracy to show on the map (Pl. 1).

A granite intrusion has been described by Burrows (1910, p. 96, 100, 103) at Chorreras (Fig. 1), south of the area studied. It has marmorized the Cuchillo and Aurora limestones for a distance of 300 feet from the contact, and the Cuchillo shales have been altered to slate. The texture of the granite is porphyritic near the contact. Lead-silver ores occur in veins west of the intrusion, and masses of hematite along the contact.

In the Ojinaga basin the Cretaceous rocks are cut by numerous dikes and sills of

basalt (Burrows, 1910, p. 102–103; Vivar, 1925, p. 8–9). About 5 miles northeast of El Nogal (Fig. 1) the Upper Cretaceous beds dips outward from a basaltic mass, possibly a laccolith.

GEOLOGIC STRUCTURE

The lower Conchos valley crosses the northern prolongation of the Sierra Madre Occidental of Mexico. South of Monterrey this range of strongly folded Mesozoic rocks follows the eastern side of the Central Plateau of Mexico. Near Monterrey the Sierra Madre forks; one branch continues to the north-northwest and the other passes westwards to the vicinity of Torreón, then swings in an arc to extend north-northwest into westernmost Texas a short distance beyond the Río Grande. The intensity of folding in the Sierra Madre is closely related to the thickness of Mesozoic strata. The strongly folded ranges are composed of a thick section of Jurassic and Cretaceous rocks. Between the two branches of the Sierra Madre and in the block-faulted ranges bordering the Sierra Madre folds in westernmost Texas, the Jurassic and the lower part of the Cretaceous section are absent; the remaining Cretaceous formations are much thinner than in the geosyncline; and the strata are not so strongly folded as in the Sierra Madre, which was formed by the intense compression of the Mesozoic geosyncline. The area between the two forks of the geosyncline is known as the Coahuila Peninsula because it was a peninsular landmass in Upper Jurassic and early Cretaceous time.

In the lower Conchos valley the folds are generally symmetrical, but in places they are overturned, some to the east-northeast and some to the west-southwest, and locally there is fan structure, with overturn on both flanks. Many normal faults strike parallel to the trends of the folds. Recent faulting in the area is indicated by evidence of a fault between the lower Las Vigas shale and the Conchos gravel northeast of Cuchillo Parado. The gravel, dipping at low angles to the west, lies in contact with east-dipping Las Vigas at the same level on the east, without evidence of normal overlap relations of the gravel upon the Las Vigas. The northeast limb of the easternmost anticline of the Cuchillo Parado area (Pl. 4) dips into the Ojinaga basin, a broad syncline filled with Upper Cretaceous rocks, the axis of which, with exposures of the youngest Cretaceous beds, passes through El Nogal (Fig. 1). Among the principal structures of the region are the El Álamo syncline, Cuchillo Parado anticline, and Sobaco syncline (Pl. 4).

The highest fold in the Placer de Guadalupe area is the anticlinal range of Plomosas limestone, which plunges northwestward and southeastward from its highest culmination south of the Mina Plomosas (Pl. 1, sections A-A′ and B-B′). In the vicinity of the Mina Plomosas the steep mountain front is bordered by a strip about 1¼ miles wide, of low ground, mostly formed of gypsiferous clay, but with some outcrops of contorted shale and limestone. This is believed to be gouge along a plane of overthrusting. Beyond are hills of Conchos gravel.

A mile and a half northeast of Placer de Guadalupe, near Boquilla, metamorphosed Plomosas beds are bordered to the northeast by a belt 0.3 mile wide of La Casita shale. Between this shale belt on the southwest and an area of probable Las Vigas shale on the northeast is a ridge of contorted dark-gray Plomosas limestone, about

0.2 mile wide. The dip across all these belts of outcrop averages 65° N.–NE., but, as the strip of Plomosas could not be intercalated in a regular succession, there is evidently faulting, and the strip of Plomosas appears to be an outlier of an overthrust sheet.

Two sharp peaks, or picachos, on each side of the railroad between San Sóstenes and Picachos stations, are formed of massive, dark-gray limestone which rests with a nearly flat contact upon the Jurassic and Las Vigas shale and sandstone in the valley between the peaks. The character of the limestone, resembling the Plomosas, and its anomalous structural relation to the Upper Jurassic—Lower Cretaceous shale below suggest that it occurs as klippe of an overthrust sheet. The distance of the farthest picacho from the Plomosas mountain front is 4 miles, representing the visible horizontal displacement along the fault.

GEOLOGIC HISTORY

If the Plomosas formation is, as herein suggested, Paleozoic, it probably was deposited in the north-trending late Paleozoic geosyncline extending north-northwest from the Pennsylvanian and Permian outcrops near Las Delicias in southwestern Coahuila to the Marfa structural basin of the western Big Bend of Texas. The Plomosas probably was folded and somewhat metamorphosed between late Permian and Upper Jurassic time, as were the Paleozoic rocks near Las Delicias.

Mesozoic sedimentation began in the Upper Jurassic and continued through the Cretaceous. Until the middle of the Aptian, deposition was limited to a geosyncline extending northward from the vicinity of Torreón to the northern end of the Quitman Mountains in trans-Pecos Texas, the landmass to the east being the Coahuila Peninsula. The areas studied by the writers were near the eastern edge of the geosyncline. In the middle Aptian, the Cuchillo formation extended across most of the Coahuila Peninsula, and the greatest flood of the Mesozoic sea followed during the deposition of the Aurora limestone and its equivalents. Uplift of land west of the geosyncline probably occurred in early Upper Cretaceous time, causing the deposition of shale and sand in the geosyncline, grading eastward, over the site of the Coahuila Peninsula, into flaggy limestone. In the later Upper Cretaceous the sea gradually receded, but deposition of continental and brackish-water sediments persisted in the geosyncline.

The entire sedimentary section apparently was folded and locally overthrust in late Cretaceous and early Tertiary time. In early Tertiary time the folded rocks were deeply eroded, stripping the nonresistant rocks from high ranges of the Plomosas and Aurora limestones. This topography is essentially the same as that along the river at present, where it has been exhumed from the Conchos gravels. A master stream removed the detritus from the region. The ranges may have been inselberge separated by pediments.

In late Tertiary time lavas were poured out upon the erosion surface. Folding recurred along pre-existing axes. Later in the Tertiary, block faults cut the area, as they did in the Big Bend of Texas and over the site of the Coahuila Peninsula. Basins of interior drainage formed, and these were filled with the Conchos gravels to a depth of about 1000 feet. Possibly the gravel surface in this area is the same

as that in the long chain of undrained or partially drained alluvial valleys or bolsons of central Chihuahua, and the gravel and lacustrine deposits of the Big Bend of Texas. The gentler slopes of the upper parts of the gorges of the present Río Conchos were evidently formed by headward erosion of streams draining into the desert basins. Further movement along normal faults evidently took place after the deposition of the Conchos gravels.

The most interesting physiographic characteristic of the present Conchos valleys is the manner in which the Río Conchos crosses numerous high mountain ranges, through deep gorges or boquillas. This also characterizes the adjacent Río Grande which, in its course of more than 250 miles in its Big Bend, crosses many mountain ranges in deep gorges, between which the river flows obliquely across the desert basins. Udden (1907, p. 15) believed the Río Grande was antecedent, and its course was determined before the present structures were all developed. Burrows (1910, p. 88–89) thought that, shortly after their upfolding, the mountain ridges of the Conchos valley retained the drainage in a parallel system of long lakes, which were filled by the Conchos gravel. When the lakes were nearly filled, minor earth movements opened passages for drainage across the mountain barriers, finally draining the lakes and determining the present course of the Conchos. As the gorges of the Río Grande and the Conchos appear to be clearly erosional rather than structural, the last part of this theory is not tenable.

P. B. King (1935, p. 256–261) pointed out that the basin deposits near the Río Grande are fine silts which show no evidence of the existence of a larger river at the time of their deposition, thus supporting the subsequent theory of Burrows and opposing the antecedent theory of Udden. According to King, thick basin deposits accumulated in structurally low areas between the ranges, which were not connected by any master stream. Eventually the basins were nearly filled by detritus, and at the lowest points of the encircling mountains they connected with adjacent basins. With an increase in rainfall in the region, master streams crossed the lowest parts of the mountain barriers to obtain outlet to the Gulf of Mexico. Later the rivers cut down through the detritus of the desert basins and the resistant rock of the buried mountains. Thus, though the Río Grande was probably not an antecedent stream, it was superimposed upon the folds buried beneath the desert basins.

As a result of the downward cutting of the Conchos and the Río Grande, the pre-Conchos gravel topography was bared near the main stream courses, leaving only remnants of the old Conchos surface, such as the Llano de Chilicote, away from the river.

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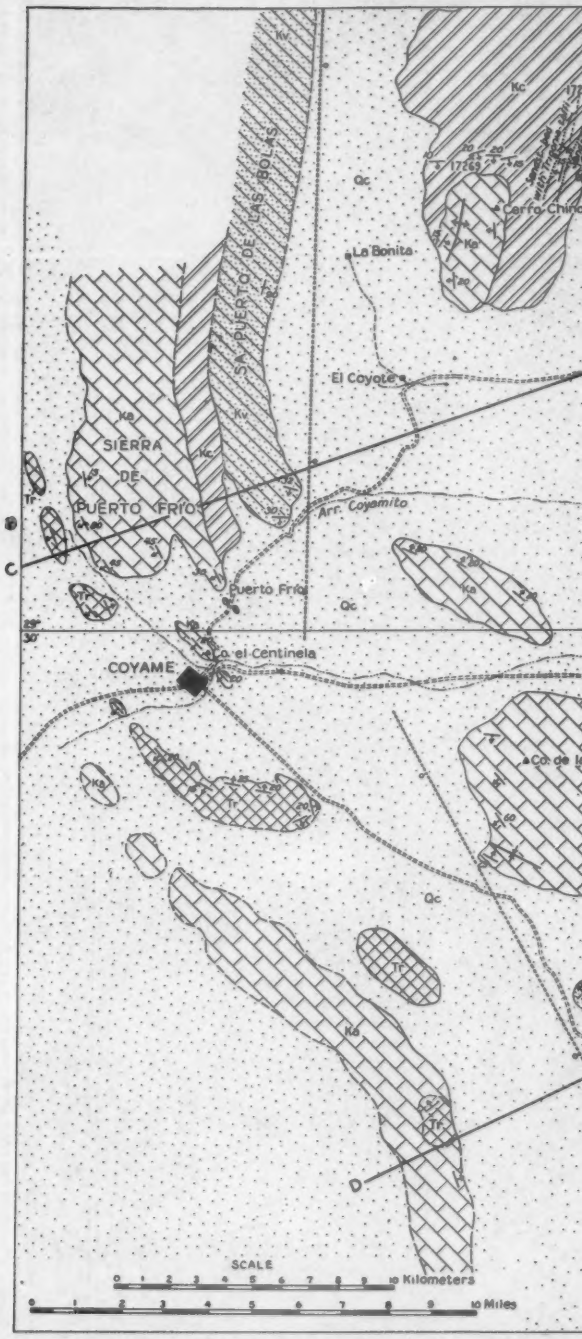
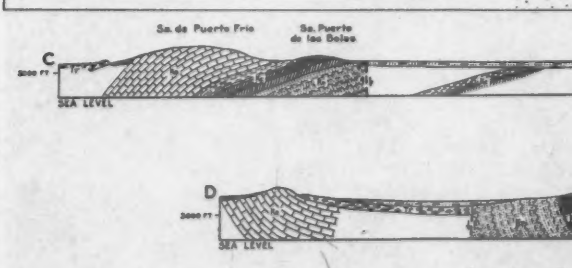
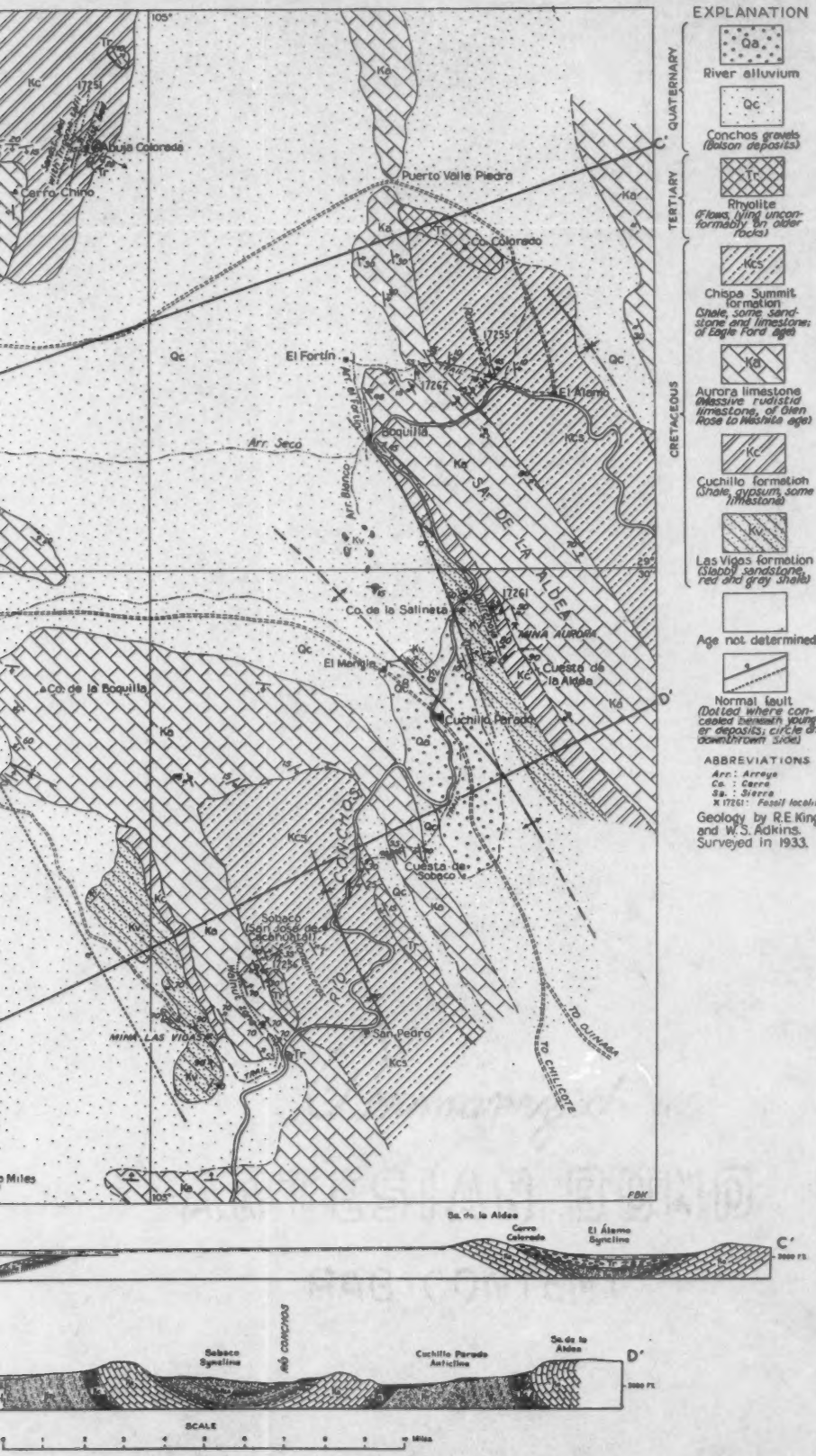




AREAL GEOLOGIC MAP ANI



MAP AND CROSS SECTIONS, CUCHILLO PARADO AREA

OFFICIAL CALENDAR

April 1–4	A. A. P. G. meeting, The Stevens, Chicago, Ill.
April 13	Meetings, committees on Publications and Projects, New York, N. Y.
April 18–20	American Philosophical Society meeting, Philadelphia, Penna.
April 19–20	Cordilleran Section meeting, University of California, Berkeley, Calif.
April 27	Council meeting, New York, N. Y.
May 3	National Research Council meeting, Washington, D. C.
May 25–26	Geographical Society Northeastern Section, Field meeting, Bethlehem, Penna.
May 27–29	American Geophysical Union meeting, George Washington University, Washington, D. C.
May 30–June 2	Field Conference of Pennsylvania Geologists, State College, Penna.